UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
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Universitat Politècnica de Catalunya

Study of a preliminary value-cost model of Earth Observation (EO) satellites operating in Very and Low Earth Orbit (VLEO/LEO) for the detection of methane emissions

Report

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Bachelor's Degree Thesis

Bachelor's degree in Aerospacial Vehicles Engineering

30th September 2019

Acknowledgements

First of all, I would like to thank Sílvia, Daniel and Miquel for having given me the opportunity to contribute in the Discoverer project, as well as for having always helped me when I didn't know how to manage the approach of the thesis.

I would also like to thank my friends for supporting and encouraging me in the hardest times, and for having learnt the full title of my thesis just to make me happy.

Finally I would like to thank my brother, for listening to me and cheering me up when I was frustrated, to my sister, for the interest and help in the writing of this thesis, and to my mum, for always being so proud of me.

Thank you all.

Declaration of honour

I declare that,
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Signed:

Alexandra Kalina Capdevila
30th September 2019

Abstract

The increase of methane emissions, as well as other greenhouse gases, is an issue to worry about. These emissions are one of the factors that cause global warming. Therefore, they should be controlled in order to decelerate the climate change. The urge for the development of new technologies for greenhouse gas monitoring is motivating the space industry to provide space-based monitoring for a global control of excessive methane sources. Although, before starting a technological development, a previous economic study has to be done. This report represents this economic study: it studies the main methane emitters, the possible costumers willing to pay, the technological requirements with its consequent costs and all the other features that have to be taken into consideration when doing an economic study. Particularly, this study is thought for a nanosatellite operating in VLEO and LEO for methane detection.

Keywords: *methane, greenhouse effect, GHG, climate change, global warming, nanosatellites, LEO, VLEO, EO, remote sensing, infrared spectroscopy, space mission, satellite imagery, value-cost model, business model CANVAS, oil and gas industry, methane leakage, methane regulation.*

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1 Introduction

1.1 Aim of the project

The aim of this project is to study the feasibility in the market of the data of methane emissions given by a small satellite operating in Very Low Earth Orbit (VLEO) and Low Earth Orbit (LEO). Moreover, a preliminary value-cost model will be estimated in order to reassure the usefulness of the project.

1.2 Scope of the project

To succeed in the development of the project certain tasks will be needed to be done:

- State of Art of the current situation of the industry of methane observation in Earth Observation (EO).
- Proceed with a further analysis of the market needs in the methane observation in EO.
- Identify the price range of the technological devices required to develop the project.
- Identify the relationship between the value of the data given by the satellite and the required cost of it studying a preliminary value-model cost of the project.
- Study of the possible extrapolation of the project to other market's opportunities.
- Analyze the environmental impact, as well as the implications and risks of the project itself.

Here below, it is shown the tasks that will not be studied in this project:

- The study of the suitable payload, referred as the technological devices, needed to be installed for the type of mission.
- Any further study of the satellite orbit.

1.3 Requirements

To develop this project, several requirements need to be accomplished. These requirements are:

- The technological devices installed will just observe methane emissions, not any other greenhouse gas.
- The satellite operating will be a small satellite, having a wet mass below 500 kilograms.
- The orbit of the satellite reaches a height between 200 and 2000 kilometres.
- Methane retrieval should be given weekly to the costumer.
- The economic study will be done considering realistic facts and the current market.

1.4 Justification

When a cow is peacefully grazing in a meadow and burbs or passes gas, as its normal digestion process, a little puff of methane is released into the atmosphere. This individual cow, plus the another 1.4 billion cattle, have the huge contribution of about 40 percent of the annual methane emissions, as part of the increasing demand for meat and dairy industry. The lack of concern from society about the climate crisis we are currently living with, enhances this situation.

Methane is the second largest greenhouse gas in the atmosphere, although there is not that much in it: about 1,800 parts per billion, about as much as two cups of water inside a swimming pool. That is about 200 times less concentrated in the atmosphere than carbon dioxide, the most abundant greenhouse gas. [1]

Even though it can be thought that methane is left in second place towards carbon dioxide, its chemical shape is remarkable more effective at trapping heat. On a 100-year timescale, methane is 21 times more powerful at warming the Earth, and this value rises up to 80 times if the timescale is cut to 20-year time. [2]

Figure 1.1: Ice melting in Greenland as an effect of global warming [3]

The existence of methane gas in the atmosphere in its proper quantity, is not harmful, but necessary for the habitability of the Earth. The problem relies on the vast impact that humankind has done towards this gas emissions. Today, scientists assure that about 60 percent of the methane in the atmosphere comes from human caused sources.

Some of this *artificial* sources are from natural procedures that have been taken to an extreme exploitation, such as the large quantity of cattle or rice paddies. Other sources come from fossil fuels extraction and manipulation, as well as landfills or waste water, all these last emitters have severely increased due to overpopulation.

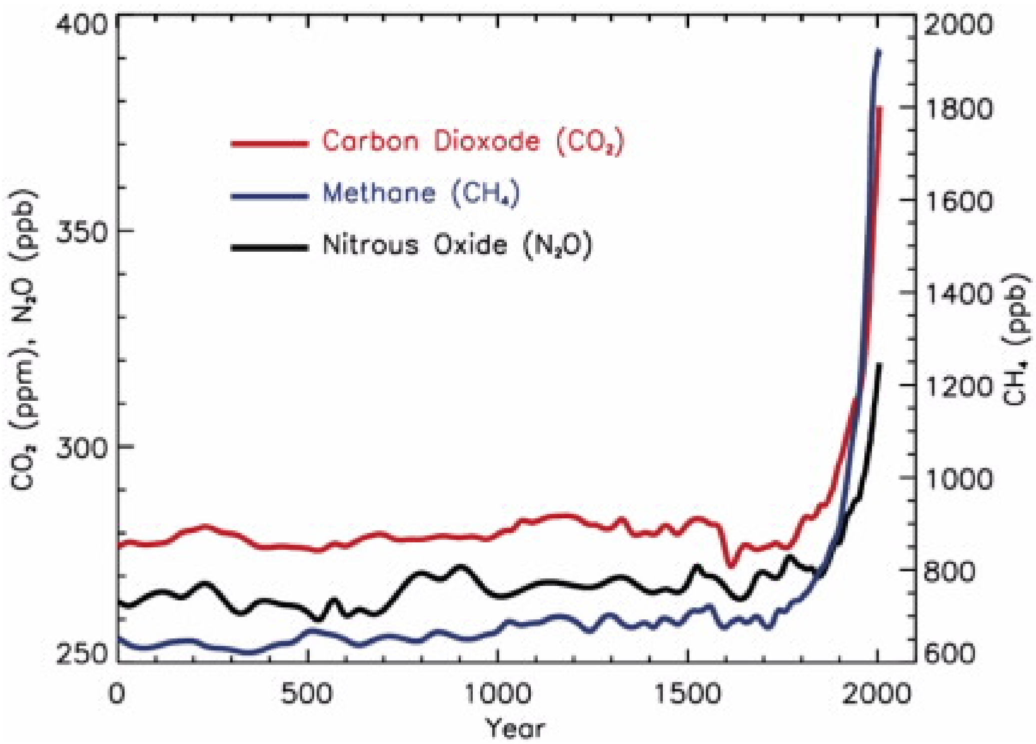

Figure 1.2: Greenhouse gases evolution [4]

Since the industrial revolution, methane emissions, as well as other greenhouse gases, have exponentially increased, rising up more than 50 percent in just a century. But this industrial revolution has not just led to bad consequences, it also has led to the technological era we are currently living in. So why don't we exploit these technological revolution, to develop instruments capable of, not cutting off greenhouse gases emissions, but at least trying to reduce them. [5]

One of the technological fields that is evolving pretty fast, is space industry. With the emergence of economic small satellites, space is an achievable place, where we have the opportunity to observe global events from space, for instance, methane emissions. This study is motivated by this purpose and has the objective to demonstrate the economic feasibility of methane detection with nanosatellites.

At the moment, there are some satellites operating with methane detection. Although, none of them are nanosatellites, so this is a great opportunity for the project to succeed. This light-weighted satellites (from 1 to 10 kg) are gaining popularity, because of its lower size, it allows a lower price, which offsets the reduced risk of failure and shorter useful life.
Even if these satellites show different features from the larges ones, it does not unable them to carry out the same tasks, and can perfectly have multiple industrial applications. [6]

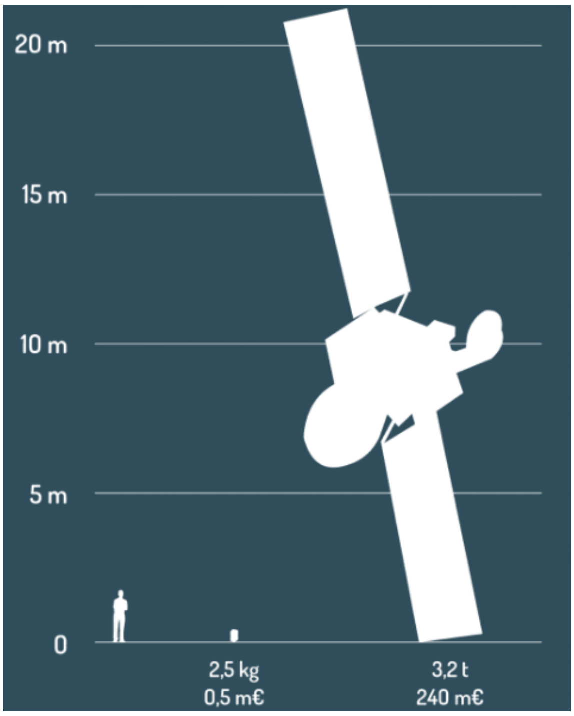

Figure 1.3: Comparison between a nanosatellite and a big satellites (Standard weights and prices). [6]

Taking advantage of all these benefits that nanosatellites have, affordable projects can be developed such as the one proposed in this report. The opportunity of monitoring methane from space can provide governmental entities or certain emitters themselves, to have a control over their emissions and be able to point their locations in order to solve the problem.
Unfortunately, there is lack of regulations and strict policies against methane emitters, in a large number of countries. Despite this, this project may give another perspective of methane monitoring, and has the aim of being an attractive economic proposal of accurate methane control for anyone interested.

2 | State of the Art

As the satellite proposed for this project is an EO nanosatellite operating in LEO and VLEO, an overview of these three concepts and a brief background of them is explained in this chapter.

2.1 Introduction to satellites

2.1.1 Definition of Satellite

A satellite is a moon, planet or machine that orbits a planet or star. The word itself is usually used for artificial satellites, machines that are launched into space that move around Earth or another body in space. [7]

2.1.2 Satellite sizes: Introduction to small satellites

Small satellites are differently defined depending on the institution: Federal Aviation Administration (FAA) refers to Small satellites when the wet mass is between 600 and 1.200 kilograms (and calls Smallsats the smaller ones), whilst National Aeronautics and Space Administration (NASA) defines them with lower mass than 180 kg. These kind of satellites are now emerging and are of great interest to satellite launch industries for applications such as remote sensing, technology development, military and intelligence, communications or science. [8]

Name	Weight (kg)
Minisatellite	100 - 180
Microsatellite	10 - 100
Nanosatellite	1 - 10
Picosatellite	0.01 - 1
Femtosatellite	0.001 - 0.01

Table 2.1: NASA's classification of small satellites [8]

In the past decade, small satellites were unusual, and just a few, no more than 15, were launched in the first five years of the century. But from 2012, small satellites launches have grown exponentially.

In the graphic below one can see the evolution of satellites launches in general highlighting in yellow the small satellites launches.

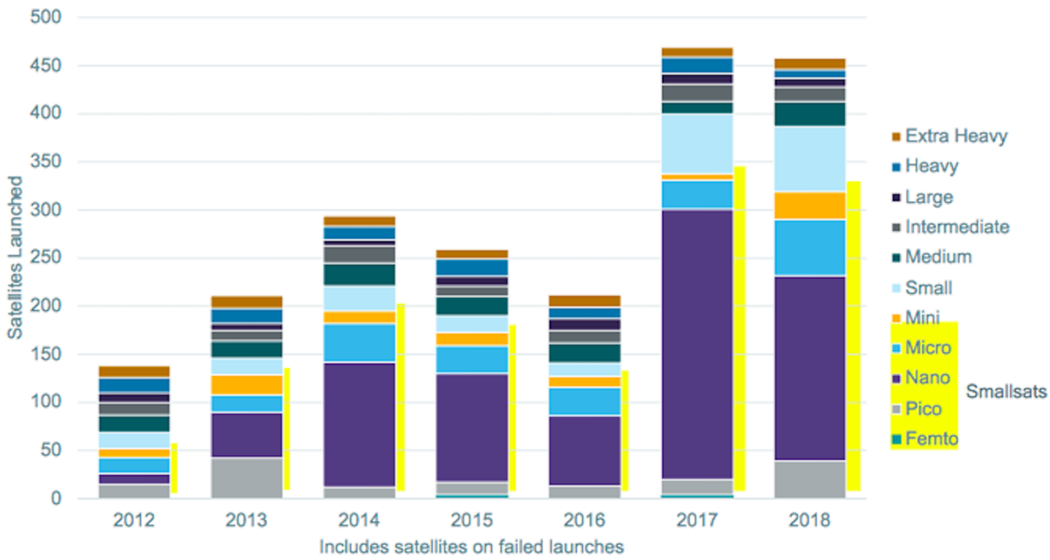

Figure 2.1: Satellites launched between 2012 until 2018 [9]

Figure 2.1 shows the satellites launched the past six years. As it can be seen, there was a crisis in satellites launches in 2014 that lasted two years. This was the consequence of the loss of 29 Smallsats in 2014, 21 in 2015 and the Falcon 9 launch failures and pad accident in 2015 and 2016, respectively. Fortunately, in the last two years this industry has flourished notably and has succeed with a high effectiveness of the Smallsats, having just lost one in the last year. [9]

It is curious that space industry did not evolve earlier into smaller satellites, taking into account that the first artificial satellite sent to the space, Sputnik, would be now classified as a small satellite. Since this first launch, satellites have grown larger and heavier, although every kilogram put into orbit would cost around $ 10.000. In the past, it was necessary to enlarge the satellites to improve the features of the satellites, but now the evolution of technology has enabled the design of smaller devices.

Obviously, the smaller the satellite is, the cheaper it is. Here below, it is shown the approximated costs of the satellites depending on their size:

Class[a]	**Cost**	**Mass**
Large satellite	$ >100 M	>1000 kg
Small satellite	$ 50 - 100 M	500 - 1000 kg
Mini - satellite	$ 5 - 20 M	100 - 500 kg
Micro - satellite	$ 2 - 3 M	10 - 100 kg
Nano - satellite	$ <1M	<10 kg

Table 2.2: Contrast of satellite's cost and mass [10]

Remark: This is another naming just to contrast the difference of price according to its weight.

This reduction of the size affects directly to the materials needed, the electrical parts number, the number of units or equipment and the working hours required for assembly and testing. Moreover, the documentation and project management costs are less, due to the reduced project complexity and the consequently smaller work team.

This main advantage of the cost reduction leads to other benefits, like a better adherence to requirements for low-budget and more tailored missions. Also this lower price is compatible with the acceptance of greater risks.

On the other hand, there are also some disadvantages like the limitations of mass and DC power can be incompatible with ambitious missions. Furthermore, small satellites have emerged recently so new procedures of thinking and management are needed as well. [11]

2.1.3 Satellite applications

In 1957, Sputnik 1 successfully launched and entered into the Earth's orbit, being the first satellite sent to space by humanity. Its main purpose then, was to test the method of placing an artificial satellite into Earth orbit,but it also provided information about the density of the atmosphere by calculating its lifetime in orbit, it enabled: testing radio and optical methods of tracking, determining the effects of radio wave propagation through the atmosphere, and checking principles of pressurisation used on the satellites; basically evaluating the features needed for the feasibility of satellites. [12]

Since this first launch in 1957, space industry has escalated quickly and the applications of satellites have diversified. We can distinguish three main areas: [13]

- **Communication satellites:** are stationed in space for the purposes of telecommunications, such as telephony, television and radio or satellite broadband. Depending on the orbit which they are put in they have a different configuration. Modern communication satellites use geosynchronous orbits, Molniya orbit [1] or LEO.
- **Navigation satellites:** are space-based radio positioning system that include one or more satellite constellations and give a three-dimensional position all day, providing users sufficient accuracy and integrity of information to be used for critical navigation application.
- **EO** is referred to the extensive satellite imagery with the main objective of analysing global environmental conditions. It is used to spot environmental disasters,monitor and manage the Earth's natural resources and analysing the state of the atmosphere, for instance, moisture analysis, cloud abundance, wind velocity,etc. The utility of different data sets for different applications are agriculture, forestry, geology, risk management, cartography, environment, weather forecast and defence.

[1] Molniya orbit is a type of satellite orbit specifically designed to provide communications and remote sensing coverage over high latitudes. It is a highly elliptical orbit, with an inclination of 63.4 degrees, and an orbit period of approximately half a day. [14]

2.2 Earth Observation

Collecting and analysing data from the Earth like physical, chemical and biological information of our planet trough remote-sensing techniques is what is called EO.

As it is one of the applications for satellites (Seen in Subsection 2.1.3), this term is thought to be just satellite-based remote sensing, but it also includes terrestrial techniques. [15]

EO includes usual numerical measurements taken by thermometers, altimeters, barometers,etc. in large scale, as well as photos and radar images taken by ocean-based instruments or by remote sensing satellites.

2.2.1 EO Satellite

It is a satellite designed for EO for different purposes. These kind of satellites show an issue: most of their instruments on board operate at a relatively low altitude, not lower than 500 - 600 kilometres usually, and at this altitude the significant air-drag make orbit reboost manoeuvres necessary. [16]

Hereafter, some features of the satellites working in EO for methane detection exposed in this report (See Section 3.3.2) are explained:

Sensors

Sensors, in satellites, are remote systems which measure energy that is naturally and artificially available. There are two types based on the source of energy [17]:

- **Passive sensor**: it is limited to detect energy just when the natural occurring energy is available. This means that reflected energy can only be measured when the sun is illuminating the Earth. Energy that is naturally emitted (such as thermal infrared) can be detected either during the day or the night, as long as the amount of energy is large enough to be recorded.

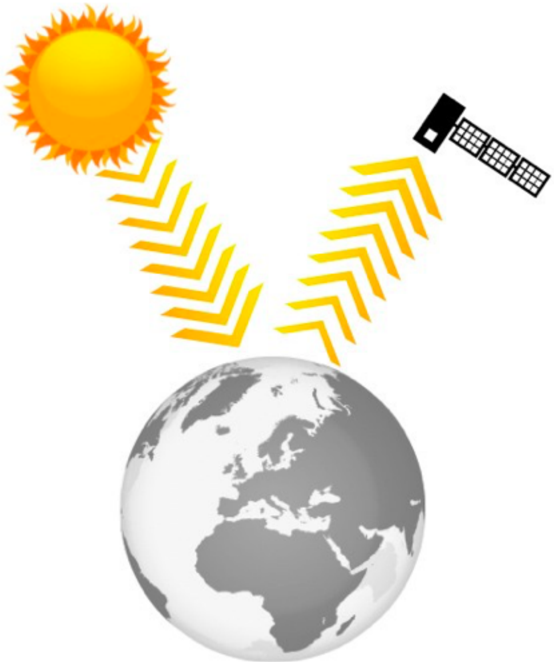

Figure 2.2: Passive sensor sensor [18]

- **Active sensor**: it provides its own energy source for illumination. The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor. These type of sensors show a great advantage: the ability to obtain measurements anytime, regardless of the time of the day. They are used for examining wavelengths that are not sufficiently provided by the sun, for instance, microwaves.

Figure 2.3: Active sensor [18]

Spatial resolution

The spatial resolution of a sensor is given by its Instantaneous Field of View (IFOV). The IFOV is the angle of view from which a signal is received by a sensor and is represented by the angle sustained by a single detector element of an optical system and the geometry of the antenna. The IFOV is independent of the sensor's altitude. The geometric projection of the IFOV onto the ground is called the Ground-projected Instantaneous Field of View (GIFOV) or Ground Sample Distance (GSD), and is determined by the IFOV and sensor height. GIFOV is the spatial resolution of the sensor. In combination with sampling rate, the GIFOV determines the spatial dimensions of the picture element (i.e. pixel) in an image. Equivalently, the angular extent of observation acquired perpendicular to the satellite's path is defined as the Field of View (FOV). The dimensions of the projected FOV onto the ground is the Ground Field of View (GFOV) or the swath width. [19]

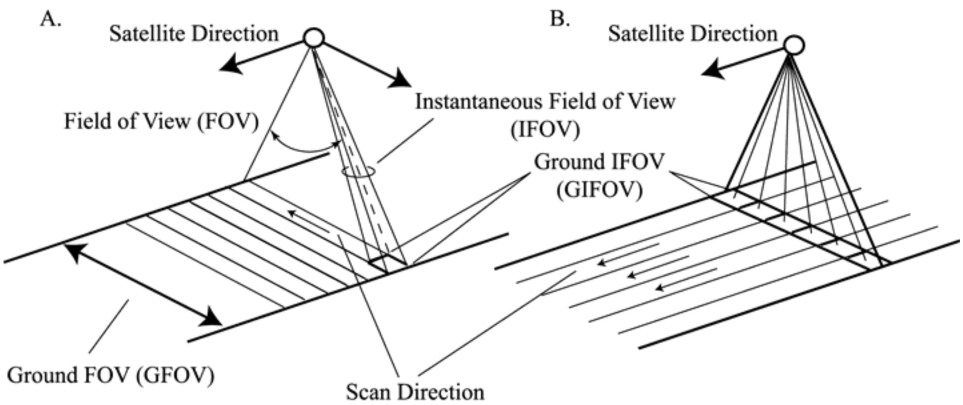

Figure 2.4: Cross track (A) and along track (B) scanners. [19]

Multispectral scanning

Satellites that work in methane detection use multispectral scanner. This consists in a scanning system used to collect data over a variety of different wavelength ranges, using a sensor with a narrow instantaneous field of view which sweeps over the terrain to build up and produce a two-dimensional image of the surface. There are two main methods of multispectral scanning: [19].

Across-track (whisk broom) scanner

It scans lines oriented perpendicularly to the direction of motion of the sensor platform. This scanners, use several detector elements, aligned in-track, to achieve parallel scanning during each cycle of the scan mirror. Each line is scanned from one side to the other of the sensor, using a rotating mirror (A) (See Figure 2.5). As the platform moves forward, successive scans build up a two-dimensional image of the Earth's surface. Ultraviolet, visible, near-infrared and thermal radiation are dispersed into their constituent wavelengths. A bank of internal detector (B) detects and measures the energy for each spectral band and then, as an electrical signal, they are converted to digital data and recorded for subsequent computer processing.

The IFOV (C) of the sensor and the altitude of the platform determine the ground resolution cell viewed (D), and then the spatial resolution. The angular field of view (E) is the sweep of the mirror, measured in degrees, used to record a scan line, and determines the width of the imaged swath (F). [19]

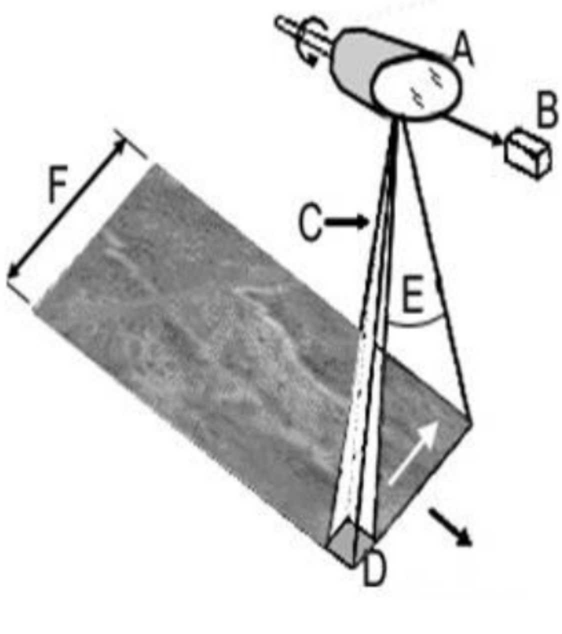

Figure 2.5: Across-track scanner [19]

Along-track (push-broom) scanner

Along-track scanners also use the forward motion of the platform to scan successive lines and build up a two-dimensional image, perpendicular to the satellite's direction. This type of scanner uses a single detector element to scan the entire scene. The difference lays on the change of a scanning mirror for a linear array of detectors (A) (See in Figure 2.6) located at the focal plane of the image (B) formed by lens systems (C), which are pushed along the track direction. Each individual detector measures the energy for a single ground resolution cell (D), hence the size and IFOV of the detectors determines the spatial resolution of the system.

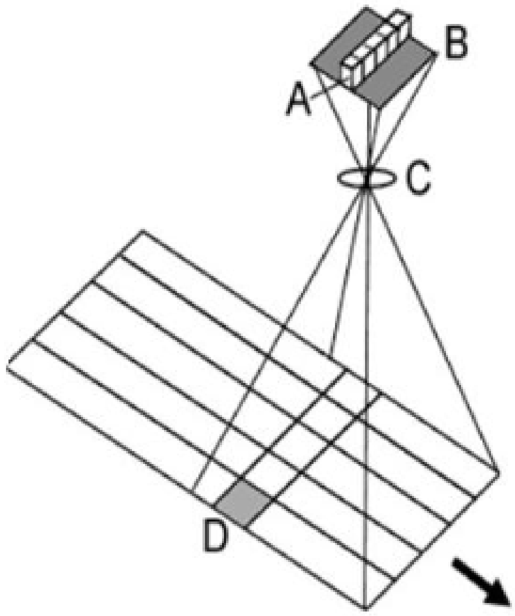

Figure 2.6: Along-track scanner [19]

2.3 Introduction to LEO/VLEO (Low and Very Low Earth Orbit)

An orbit is defined as a path of a body revolving around an attracting centre of mass, as a planet does around the Sun or a satellite around a planet, caused by the gravitational forces between the two bodies.

Orbits are elliptical, if they are not affected by the attraction of another planet. Although, some of these elliptical orbits are nearly circles. [20]

Considering circular the orbits around the Earth, we can differentiate three main types of satellite orbits: LEO, MEO and GEO (Geostationary Earth Orbit) by their altitude from the Earth. A brief comparison of the orbits is shown below:

Satellite Feature	**GEO**	**MEO**	**LEO**
Orbital period	24 hours	2 to 8 hours	10 to 40 minutes
Satellite height	35.758 km	2.000 - 35.758 km	200 - 2.000 km
Satellite life	Long	Long	Short
Propagation loss	Highest	High	Low

Table 2.3: Comparison between different type of orbits [21]

The table shows the more relevant differences between the different orbits. This project is centred in LEO so then a further analysis of its advantages and drawbacks will be explained. [22]

On one hand, the fact of this closeness to the Earth improves certain features like:

- A better signal strength, hence less power is needed for transmission.
- Least propagation delay, consequently lower latency feasible for real time critical applications.
- Low price satellite equipment is sufficient for ground stations.

On the other hand, the proximity to Earth interferes with other parameters such as:

- A minor coverage of the Earth due to the closeness to it. In order to cover a larger region more satellites are needed.
- This satellites move constantly, then the service is being handed off by each satellite to the next one in the constellation. Hence succession of satellites is required to cover any region on Earth.
- Atmospheric effects are higher and this can cause gradual orbit dis-orientation.
- It is only visible for 15 to 20 minutes from a particular area of Earth, so there is less time for testing and troubleshooting.
- They have shorter life span (5 to 8 years) compared to GEO (10 years).

3 Methane detection market

In order to develop this study, an acknowledgement of the methane topic is needed. In this chapter, a brief introduction to the methane situation is explained, as well as its detection instruments and its current detection market.

3.1 Greenhouse effect and methane overview

The greenhouse effect is a current issue to worry about. This consists in a natural process that warms the Earth's surface. When the solar radiation reaches the Earth's atmosphere, the oceans and land absorb some of this heat and the rest is radiated back from the Earth towards the space. Some of this heat emitted by the Earth is trapped by greenhouse gases (GHG) present in the atmosphere, heating the its surface as the natural procedure. The excess of these GHG emission leads to an overheating. [23]

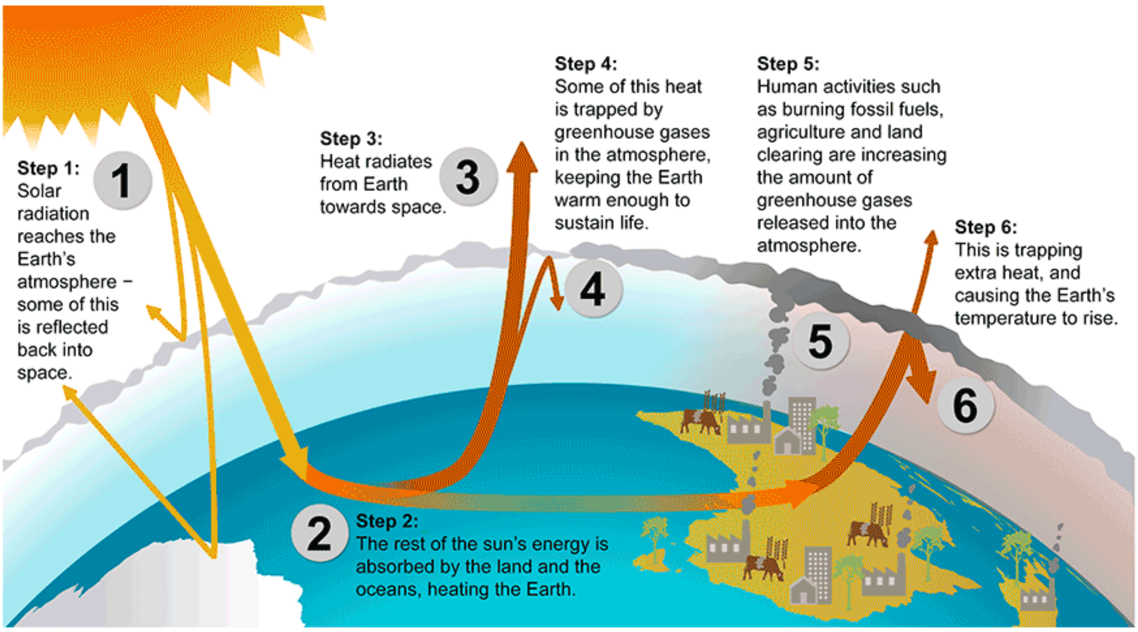

Figure 3.1: Explanation of the greenhouse effect [23]

The gases that cause this greenhouse effect are the following ones: carbon dioxide, methane, nitrous oxide and fluorinated gases, in order of their emissions. Carbon dioxide seems to get all the attention, due to the fact that it is the largest emitter, representing 81% of the GHG, but there is another gas that has to be taken into consideration because of its harmful effects: methane.
In comparison to carbon dioxide, methane has a lower concentration on the atmosphere but is equally important as it its 21 times more potent per unit as a GHG.

In the following table it is shown different aspects of the GHG:

Gas	**% of emission**	**GWP***	**Atmospheric life (years)**
CO_2	81	1	5 to 200
CH_4	10	21	114
N_2O	6	310	114
HFC	1	140 to 11.700	1,4 to 260
PFC	1	6.500 to 9.200	10.000 to 50.000+
SF6	1	23.900	3.200

Table 3.1: Comparison of the different GHG [24]

The potency of the greenhouse effect is the radiative forcing which measures how much the GHG affect the balance of heat coming and going in and out of the atmosphere.

The Global Warming Potential (GWP *) is calculated by the relative contribution of this Greenhouse effect over 100 years in comparison, over the same period, of an emission of 1 kg of carbon dioxide. Then the meaning of the GWP of methane being 21, means that the impact of this gas is equivalent to the emission of 21 units of mass of carbon dioxide in 100 years. [24]

3.1.1 Evolution of methane emissions

The methane emissions have grown exponentially since the industrial era began. In 1905 there were 883 ppb (part-per-billion) of methane in the atmosphere, while in the last year there were 1867,2 ppb, meaning that the emissions have risen up to a 53% in a century.

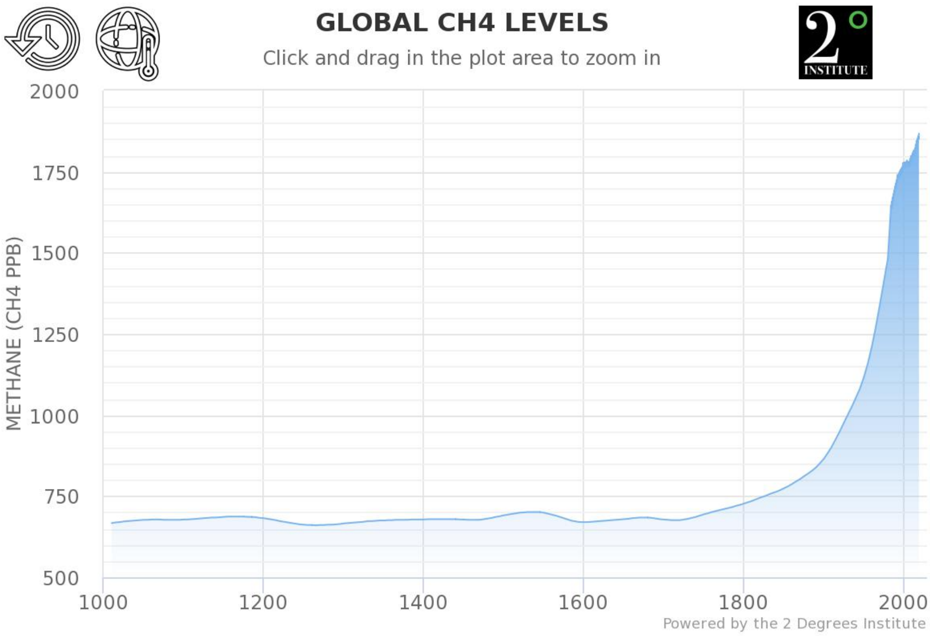

Figure 3.2: Global levels of methane from 1000 to 2018 [25]

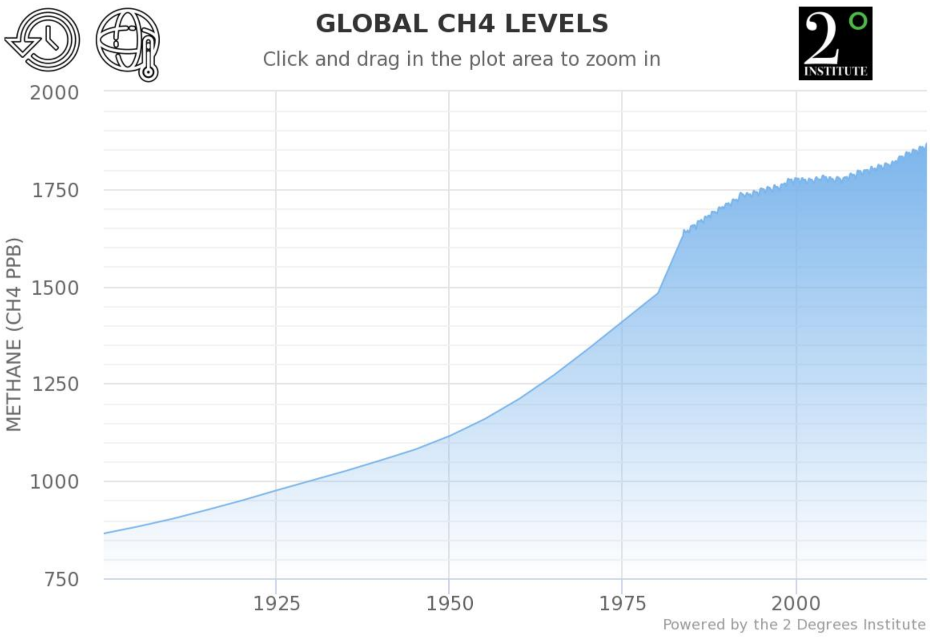

Figure 3.3: Global levels of methane from 1900 to 2018 [25]

As it is shown in Figure 3.2, global methane emissions have increased extraordinarily since the industrial revolution emerged. This represents a problem for the Earth's sustainability as it is not prepared to have such an amount of GHG concentration on air.

Furthermore, as it is noticeable that in Figure 3.3, where the evolution of methane emissions in the last century is shown, these are not being reduced. One can see a semi-linear evolution until 1980, that there was a sudden leap and ever since then it has been constantly increasing and reaching maximum levels that are dangerous. This may be caused by different factors, like the growing accessibility to travel with different vehicles, the growth of landfills due to an excess residues or the harmful effects of the cattle.

3.1.2 Main methane emitters

The natural origin of methane emissions comes from either geological sources or biological sources, both of them share the same basis: natural procedures of organic matter in anaerobic conditions, either decomposition of the matter or as a result of a biological procedure called methanogenesis[1]. [26]

It is difficult to quantify exactly the emissions of methane worldwide but the probes show that the main emitters in ascending order are: stationary and mobile sources, biomass burn, coal mining, manure used for agriculture, other agricultural sources, waste water, landfills, rice production, petroleum and natural gas and enteric fermentation from cattle.

Following, it is explained how the main emitters contribute:

- The cattle bred affects in two of the major issues of methane emissions, on one hand, animals such cows, sheep or goats are ruminant animals that during their digestive process they emit heaps of methane. On the other hand, any animal breed to the meat industry produces manure that the farm has to treat for hygienic reasons, and also used for agriculture, anyway this procedure also contributes in large methane emissions.

[1]Methanogenesis: is a form of anaerobic breathing of microorganisms called methanogens. They are found in landfills, soil and rumiant animals. [27]

- Fossil fuel emits methane during normal procedures of petroleum, natural gas or coal extraction. Operations such the manipulation, processing and transportation of these materials produce methane as well.
- The landfills are full of organic matter, and the pile of trash left in these places leads to a breakdown in anaerobic conditions, in which methane is released, in the case of the lower parts of these garbage stacking.
- Another important emitter that is less obvious and known is rice production. This is not because the plant itself emits this gas, the emission is produced because of the flood conditions that avoid the contact of the soil with oxygen, this creates anaerobic conditions and happens the same as in landfills. [28]

Here below it is shown a circle chart with the main emitters of this gas:

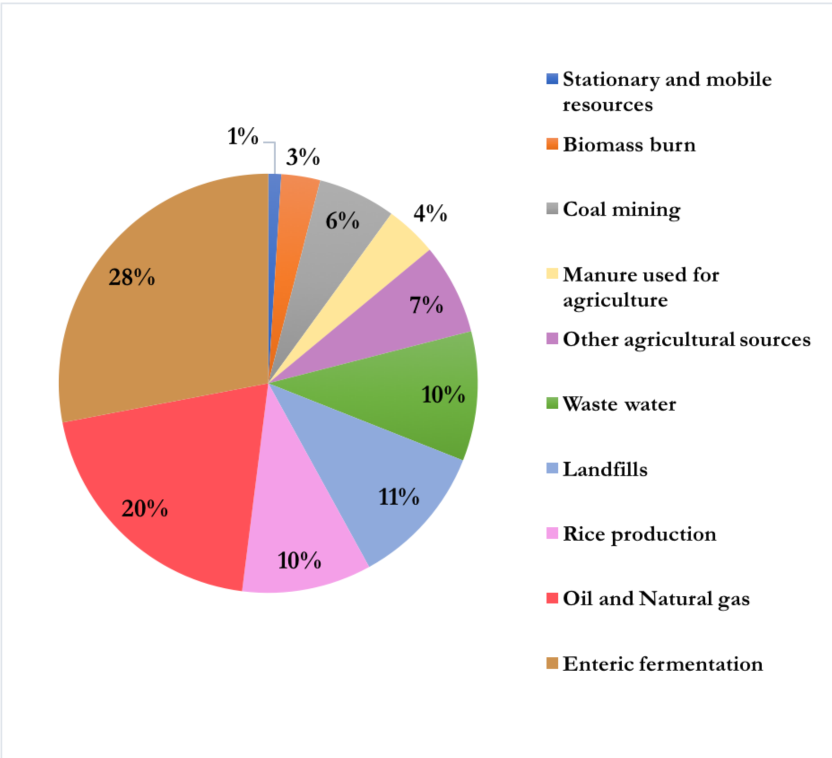

Figure 3.4: Methane emitters worldwide [29]

3.2 Current market situation

As it is understandable, most of the applications that EO provide have previously been developed on Earth. Therefore, to evaluate current situation of the methane detection market it will be first seen the methane detection technologies on Earth, and after that, the ones used with satellites.

3.2.1 Overview of methane detection instruments

The methane detection market has evolved in the last years and shows a variety of techniques of detection. Methane measurements are done in a wide range of spatial and temporal scales: from large-scale global assessments of annual emissions to small-scale measurements of emissions from individual sources over short timescales (e.g., instantaneous).

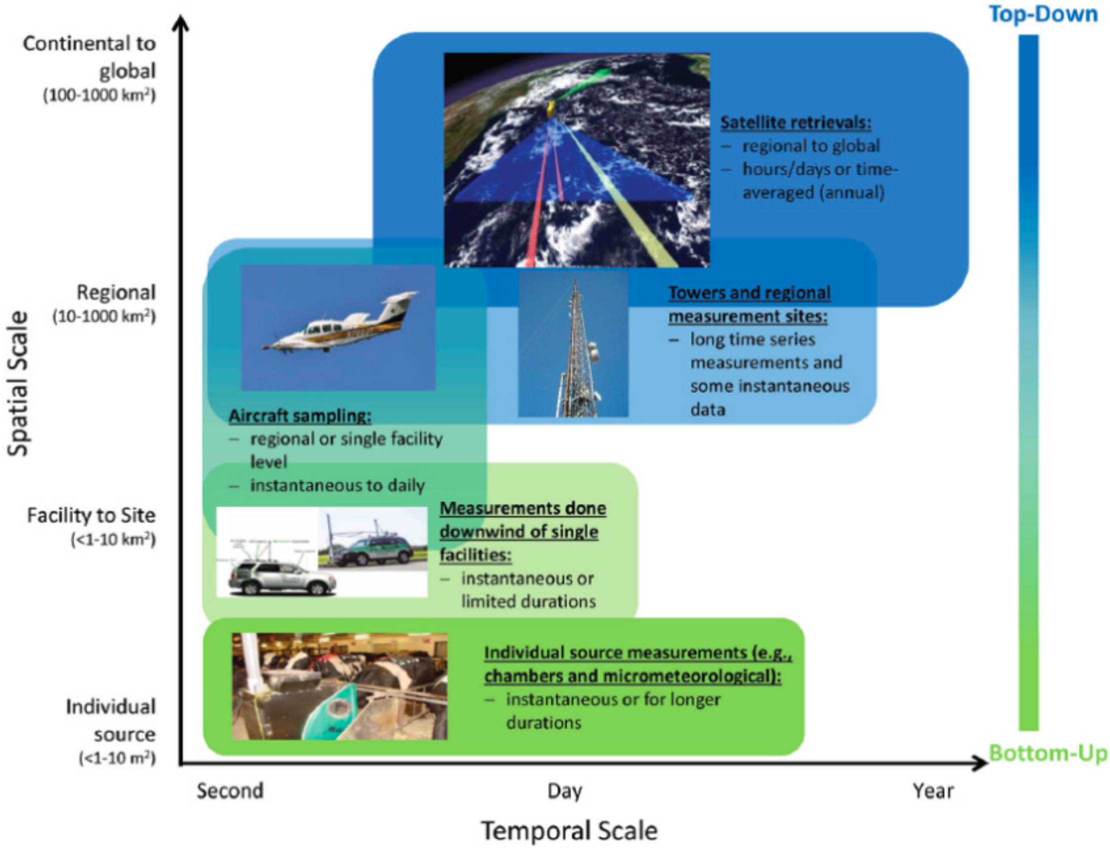

Figure 3.5: Examples of methane measurement platforms operating accross a variety of spatial and temporal scales [30].

At smaller spatial scales, measurements come from single processes, individual sources or components within a facility are extrapolated to larger scales (regional, national and global). These techniques are called bottom-up and they are more representative for broader geographic areas. Bottom-up techniques are briefly explained in Table 3.2.

Inversely, at larger spatial scales (e.g.,global,continental and regional), atmospheric methane concentrations can be transformed, using different modelling tools, to estimate methane emissions from broad geographic areas. These emissions estimates, which aggregate emission from multiples sources, are called top-down assessments. An overview of top-down instruments is explained in Table 3.3.

Technique	Method	Advantages	Disadvantges
Point-source measurements	◦ Measurement of emissions from fixed points based on flow rate and methane composition.	◦ Measures total methane emissions from individual point sources. ◦ Captures temporal trends if deployed for extended time periods.	◦ Limited number of methane sources are emitted as point sources. ◦ Labour intensive to quantify spatial and temporal variability (requires a large number of individual measurements to capture variability.) ◦ Often limited to measurements from standard operations or where there are no safety concerns.
Enclosure (chamber) techniques	◦ Direct measure of emissions from small area (or number of animals). ◦ Static chambers quantify emissions by multiplying the change in methane concentration over short monitoring periods by the chamber volume/area ratio. ◦ Dynamic chambers quantify emissions by the use of inlet/outlet methane concentrations with an external flux gas known rate.	◦ Quantifies diffusive emissions rates from a small source area (typically 1m^2 or less) during the daytime or nighttime conditions. ◦ Accurately measures emissions from individual or small groups of animals in a controlled environment. ◦ Does not rely on atmospheric modelling to derive fluxes. ◦ Quantifies rates for solid oxidation of atmospheric methane	◦ Labour intensive to measure the variability of emissinos over large source areas (requires geostatical techniques, a large number of chamber measurements, and ancillary information). Provides an instantaneous measurements that must be repeated to capture temporal trends. ◦ Single enclosures may not capture all variability in emissions.

(Continues in the following page)

Technique	Method	Advantages	Disadvantges
Micrometeoro-logical techniques	○ Tower-based vertical measurements of gas concentrations and atmospheric parameters with standard modelling approaches to calculate fluxes.	○ Measures total methane emissions from individual sources/small open source areas. ○ Measures continuously over time to capture temporal trends in emissions. ○ Measures uptake of atmospheric methane	○ Difficult to measure the variability of the emissions depending on the ratio of the technique's footprint to the overall source area and therefore may over- or underestimate emissions. ○ Appropriate topographic and meteorological conditions are necessary for technique to work properly. ○ Nighttime measurements are difficult to achieve.
Perimeter facility line measurements	○ Measurement of path-integrated methane along boundaries of a source area along with wind characteristics to estimate an emission rate.	○ Measures total methane emissions from variable-sized source areas. ○ Allows long-term continuous monitoring to capture temporal trends in emissinons.	○ Difficult to isolate the different sources in source areas depending on distribution and meteorological conditions. ○ Appropiate topographic and meteorological conditions are necessary for technique to work properly. ○ Difficult to determine the area contributing to flux.
External tracer	○ Release of tracer gas (C_2H_2 and N_2O) at known rate from source area. ○ Measurements of methaane and tracer concentratinos across well-mixed downwind plumes to derive emission rate.	○ Measures total methane emissions from source area. ○ Measures complex sources or quantifies the uncertainty in the emission estimation.	○ Difficult to isolate individual sources within source area depending on layout and meteorological conditions. ○ Appropiate meteorological conditions are necessary for technique to work properly. ○ Vulnerable to bias if the locations of tracer release differ significantly from the location of methane release. ○ Labour intensive to measure the spatial and temporal variability of emissions over many sources.

(Continues in the following page)

Technique	Method	Advantages	Disadvantges
Inverse dispersion modelling	○ Measurement of downwind methane concentrations with estimated or measured meteorological parameters to estimate the flux rate from point and area sources.	○ Estimates total methane emissions from point and area sources. ○ Estimates temporal trends when measurements are made continously.	○ Difficult to isolate various sources within the source area depending on source layout and metorological conditions. ○ Reliant on modelled meteorological conditions, which may differ from reality and/or limited field measurements. ○ Regional-scale methods are not fully developed. ○ Accuracy may vary depending on the source to be measured.
Facility-scale in situ aircraft measurements	○ Multiple vertical measurements of atmospheric methane and wind-speed gradients above a source area to derive an emission rate.	○ Remote measures total methane emissiosn from a source area/ facility regardless of the operational status or safety conditions at the facility. ○ Captures temporal trends with repeated overflight.	○ Generally cannot isolate individual source within source area unless source-specific tracer can be co-quantified. ○ Specific meteorological conditions are necessary. ○ Requires multiple flights to capture temporal trends in emissions. ○ Generally limited to higher-emitting sources. ○ Labour intensive to measure the spatial and temporal variability of emissions over many sources.

Table 3.2: Bottom-up techniques for measuring methane emissions [30]

Technique	Method	Advantages	Disadvanges
Remote observatories	○ Atmospheric methane by infrared spectrometry at precise infrared wave-lengths for "pristine" sites remote from population centres. ○ Other radiatively active gases and hydrocarbon gases are also measured.	○ High precision. ○ Consistent measurements across multiple sites. ○ Longtime series.	○ Limited spatial coverage.

(Continues in the following page)

Technique	Method	Advantages	Disadvanges
Towers	○ Methane by infrared spectrometry at precise infrared wavelengths. ○ Time-series measurements of concentrations, analysed by eddy co-variance or by inverse modelling.	○ High precision. ○ Consistent measurements across multiple sites. ○ Longtime series.	○ Sparse spatial coverage potential small sensitivity footprint. ○ Methods are not fully developed. ○ Challenging to apply to individual facilities and distinguish confounding sources.
Aircraft mass balance measurements	○ Measurements upwind and downwind of source region. ○ High-time resolution instruments. ○ Infrared spectrometry at precise infrared wavelengths.	○ Ability to target specific emission source regions and obtain vertical profiles of methane concentrations. ○ Analysed using simple flow-through models and/ or sophisticated inversion modelling.	○ Limited spatial and temporal coverage limited to a snapshot. ○ Labour intensive to measure the spatial and temporal variability of emissions.
Aircraft remote sensing measurements	○ Absorption spectroscopy using reflected sunlight or thermal emissions.	○ Ability to map methane plumes at the 1-5 scale, direct source attribution.	○ Limited spatial and temporal coverage. ○ Not as accurate as in situ data.
Satellite	○ Absorption spectroscopy using reflected sunlight or thermal emissions.	○ Global, complete spatial coverage, frequent revisit time with a single instrument.	○ Coarse spatial resolution with current instruments. ○ Not as accurate as in situ data, emissinos not cleanly resolved. ○ Limited to good visibility conditions.

Table 3.3: Top-down techniques for measuring methane emissions [30]

3.3 Spatial methane detection

In this section, it will be explained the different techniques used for methane detection in EO and afterwards, there are briefly explained other missions that are currently working in methane.

3.3.1 Methodology of spatial methane detection

Atmospheric methane is detectable by its absorption of radiation in the short wave infrared (SWIR) at 1.65 and 2.3 μm, and in the thermal infrared (TIR) around 8 μm.

The SWIR technology measures the solar radiation backscattered by the Earth and its atmosphere, and the TIR instruments measure the blackbody terrestrial radiation absorbed and re-emitted by the atmosphere. [31]

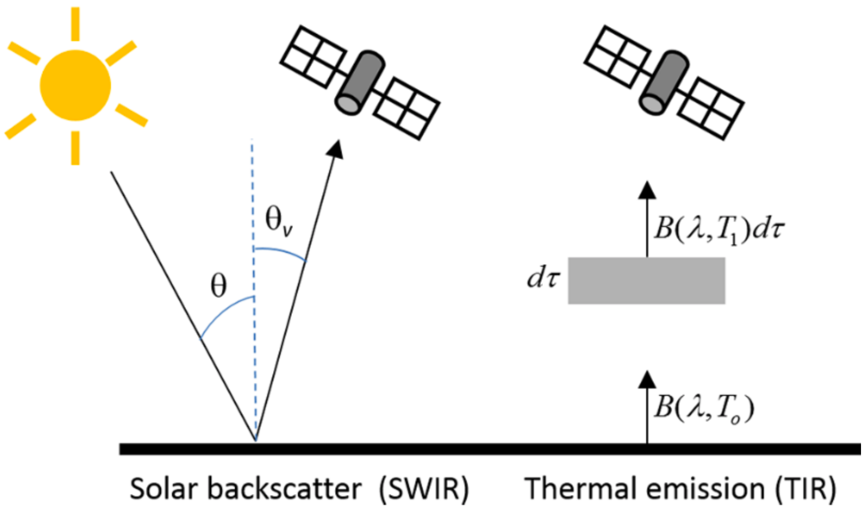

Figure 3.6: Satellite configurations in SWIR and TIR [31]

In Figure 3.6, it is shown the two different configurations for observing methane from space. The angle θ is the solar zenith angle, θ_v the satellite viewing angle, B (λ, T) is the black body function of wavelength and temperature T, (T_0 at the surface, and T_1 at the altitude of the emitting methane), and d is the elemental methane optical depth.

The sensitivity of the instruments for solar backscatter are a crucial parameter for an optimal retrieval. This sensitivity changes for SWIR and TIR instruments, as it is shown in Figure 3.7,SWIR instruments measure the total atmospheric column of methane with near-uniform sensitivity in the troposphere. Meanwhile, TIR measurements require a thermal difference between the atmosphere and the surface and this limits their sensitivity to the middle and upper troposphere. [32]

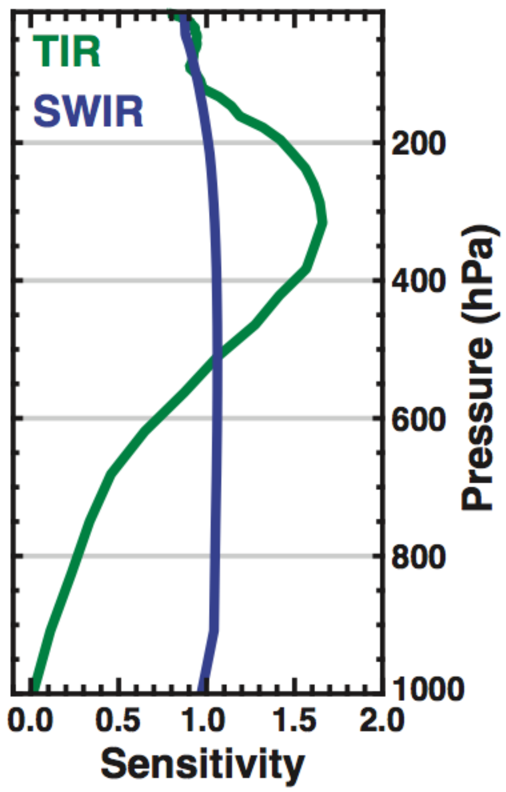

Figure 3.7: Typical sensitivities as a function of atmospheric pressure for satellite observation of atmospheric methane in SWIR and in TIR. [33]

As it was previously mentioned, methane can be absorbed at 1.65 and 2.3 μm bands. In Figure 3.8, methane absorption or optical depth is highlighted with other different gases. Most of the current operating methane detector satellites, operate using the 1.65 μm band, not only for methane retrievals, but also for carbon monoxide. As it is seen by its absorption specter of methane, the 2.3 μm band is stronger. However, solar radiation is three times weaker in this band.

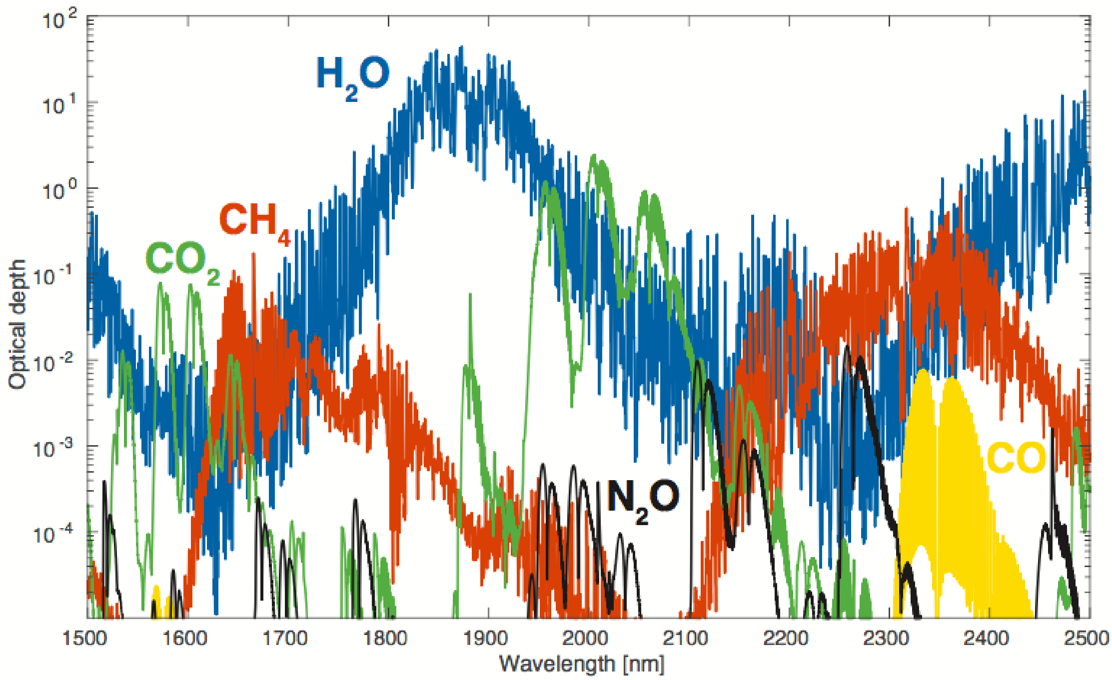

Figure 3.8: Atmospheric optical depths of major trace gases in the spectral region 1.5–2.5 μm. [34]

A drawback that the SWIR technology shows, is that it requires a reflective surface for solar backscatter measurements. This limits its measurements to land, although some ocean data can be obtained from spectral reflection at the ocean surface. Another important disturbing element are clouds. Condensed air affects the retrieval by reflecting solar radiation back to space and preventing detection of the air below the cloud. Even partly cloudy scenes are problematic because the highly reflective cloudy fraction contributes disproportionately to the total backscattered radiation from the pixel.

There are two methods for methane retrieval at 1.65 μm: [35]

- The full-physics method: where the scattering properties of the surface and the atmosphere are fitted as part of the retrieval, and then using additional fitting varibables the scattering is described.
- The CO_2 proxi method: where the spectral fit for methane ignores atmospheric scattering, and the resulting methane column is subsequently corrected for scattering by using a separate retrieval of CO_2.

Once methane is retrieved, the data is modelled. The general approach used for inferring methane emissions from observed atmospheric concentrations is to use a 3-D chemical transport model (CTM). This model simulates atmospheric transport on the basis of assimilated meteorological data for the observation period and a 2-D field of gridded emissions. It computes concentrations as a function of emissions by solving the mass continuity equation that describes the change in the 3-D concentration field resulting from emissions, winds, turbulence, and chemical loss. [35]

3.3.2 Satellites operating in methane detection

Here below there is a table with the operating satellite instruments used for measuring tropospheric methane:

Instrument	Agency ^{a}	Launch	Pixel size[km^2]^b	Coverage^c
Solar backscatter				
GOSAT	JAXA	2009	10 x 10	3 days
TROPOMI	ESA,NSO	2017	7 x 7	1 day
GHGSat	GHGSat, Inc.	2018	10 x 10	1 day
GOSAT - 2	JAXA	2018	10 x 10	3 days
Thermal emission				
AIRS	NASA	2002	45 x 45	Half day
IASI	EUMETSAT	2007	12 x 12	Half day

Table 3.4: Satellites operating currently in methane detection [36]

Remarks: Agency^a : ESA = European Space Agency; JAXA = Japan Aerospace Exploration Agency, NSO = Netherlands Space Office, GHGSat, Inc. is a private Canadian company.; NASA = US National Aeronautics and Space Administration; EUMETSAT = European Organization for the Exploitation of Meteorological Satellites; NOAA = National Oceanic and Atmospheric Administration. Pixel size [km^2]^b : At the subsatellite point. Coverage ^{c} : Time required for full global coverage.

All instruments launched to date have been in polar sunsynchronous LEO. They detect methane in the nadir along orbit track, and most also observe off-nadir (at a cross-track angle) for additional coverage.

GOSAT-1

GOSAT - 1 (Greenhouse Gases Observing Satellite, also nicknamed Ibuki meaning "breath" or "puff") is a JAXA mission within the Japanese Global Change Observation mission. It was launched on the 23rd of January of 2009 in Tanegashima Space Centre. [37]

Its main objective, as its name says, is to provide global measurement of carbon dioxide and methane basically. It is equipped with two different instruments: the Thermal And Near Infrared Sensor for carbon Observation-Fourier Spectrometer (TANSO-FTS) and the Cloud and Aerosol Imager (TANSO-CAI).

Figure 3.9: Render of GOSAT-1 [38]

The payload used for the detection of Greenhouse Gases is the TANSO-FTS. This one has four spectral bands, three of them operate in SWIR providing sensitivity to the near-surface absorbers covering the wavelenght ranges from 0.758-0.775, 1.56-1.72, 1.92-2.08 μm, and the fourth channel operates in thermal infrared providing mid-tropospheric sensitivity.

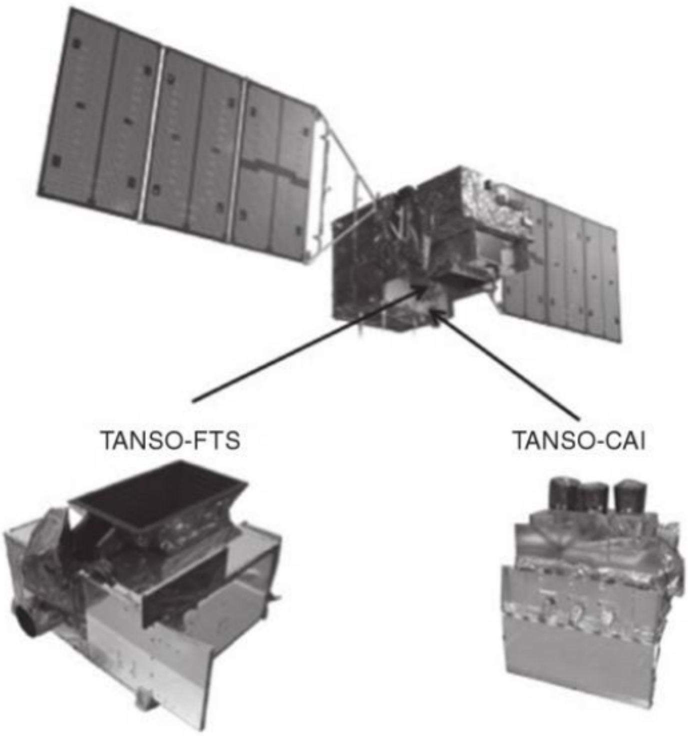

Figure 3.10: GOSAT-1 configuration [39]

The measurement procedure of TANSO-FTS is optimized for the characterization of continental-scale sources and sinks. These measurements nominally consist of 5 across-track points, separated by approximately 100 km, with a ground footprint diameter of almost 10,5 km.

Other important features of the GOSAT, are its orbit altitude, notice that it is LEO, about 666 km, and its mass, being of about 1750 kg at launch. Since there is a new version of the GOSAT currently working, (GOSAT-2, explained in subsection 6.4), this mission is estimated to end the mission in 2019, and let its follower provide the data that GOSAT has this past years. [40]

Sentinel-5

TROPOMI was launched as single payload aboard the Sentinel-5 Precursor satellite on the 13th of March of 2017. It is a mission set by ESA and NSO, with the objective of the study of the atmosphere chemistry. The satellite is classified as a medium satellite weighting 980 kilograms and operates in LEO (approximately at 824 kilometers). Its mission is supposed to end by the year 2024. [41]

Figure 3.11: Render of Sentinel-5P [42]

TROPOMI is a passive remote sensor that operates in push-broom configuration, with a swath width of approximately 2600 km on the Earth's surface. Its spatial resolution near nadir is around 7 x 3.5 km^2 for all spectral bands, except for the UV1 band (7 x 28 km^2) and the SWIR band (7 x 7 km^2), providing a full-surface coverage within a day, since its orbit period is 100 minutes.Its spectral range goes from: 0.270 μm to 0.495 μm, 0.710 μm to 0.775 μm and 2.305 μm to 2.385 μm. [43]

Within the payload, there are two spectrometer modules, the first containing the ultraviolet, visible and near-infrared (NIR) spectral bands and the second dedicated to the shortwave infrared (SWIR) band.

Supposedly, for methane detection the two modules are used following the same retrieval algorithm as with GOSAT. However, the NIR band suffers from straylight and calibration problems, and until it is solved, the SWIR band is the only one used for the atmospheric methane detection. [44]

GHGSat

GHGSat was launched on the 21st of June of 2016, it does not belong to any big agency, it is a singular mission develop by the company GHGSat. The main objective of the mission is to provide remote sensing of GHG, air quality, and traces of gas emissions. Basically all the observations focus on oil and gas facilities, power stations, coal mines, landfills, animal feedlots and other natural resources.

Figure 3.12: Render of GHGSat [45]

GHGSat also nicknamed as “CLAIRE” has a payload that includes two sensors: a 2-D Wide-Angle Fabry-Perot (“WAF-P”) imaging spectrometer in short-wave infrared (SWIR) (capturing spectres from 1.6 μm and 1.8 μm), and a Clouds and Aerosols (“CA”) sensor. The first one measures vertical column densities of carbon dioxide and methane, whilst the second one measures interference from clouds and aerosols in the field of view of the WAP-F.

CLAIRE is considered a microsatellite, since it weights less than 15 kilograms. It also operates at LEO approximately at an altitude of 500 km. The mission’s end is planned to be by the year 2021, although the company will have already launched two high-resolution satellites (GHGSat-C1 and GHGSat-C2) in 2019. [46]

GOSAT-2

GOSAT-2 is the following mission to GOSAT-1 (seen in subsection). It is an improved version that has the same objective: study the atmospheric chemistry. It was launched on the 29th of October of 2018 and is supposed to be operating until 2023. [47]

While GOSAT can observe different greenhouse gases such as: carbon dioxide, methane, ozone and water vapour, GOSAT-2 also measures the emissions of carbon monoxide and nitrogen dioxide.

Figure 3.13: Render of GOSAT-2 [48]

The instruments on board the satellite are the same as the ones on its precursor: TANSO-FTS and TANSO-CAI. The improvements on the spectrometer are a wider along-track coverage, an additional spectral range to observe more of these greenhouse gases and new technology to provide intelligent pointing.

Other small differences with GOSAT-1 are its mass at launch which was 50 kilograms below, a 53 kilometre lower orbit altitude and an increase of the 32% in the spacecraft power. [49]

AIRS

The Atmospheric Infrared Sounder (AIRS) launched on board of Aqua satellite, in polar orbit, on the 4th of May 2002. AIRS was designed to measure the Earth's atmospheric water vapor and temperature profiles on a global scale: it measures clouds, abundances of trace components in the atmosphere including ozone, carbon monoxide, carbon dioxide, methane, and sulfur dioxide, and detects suspended dust particles. The total mass at launch was 2,934 kg and it operates at a sun-synchronous circular orbit, in an altitude of 705 km. [50]

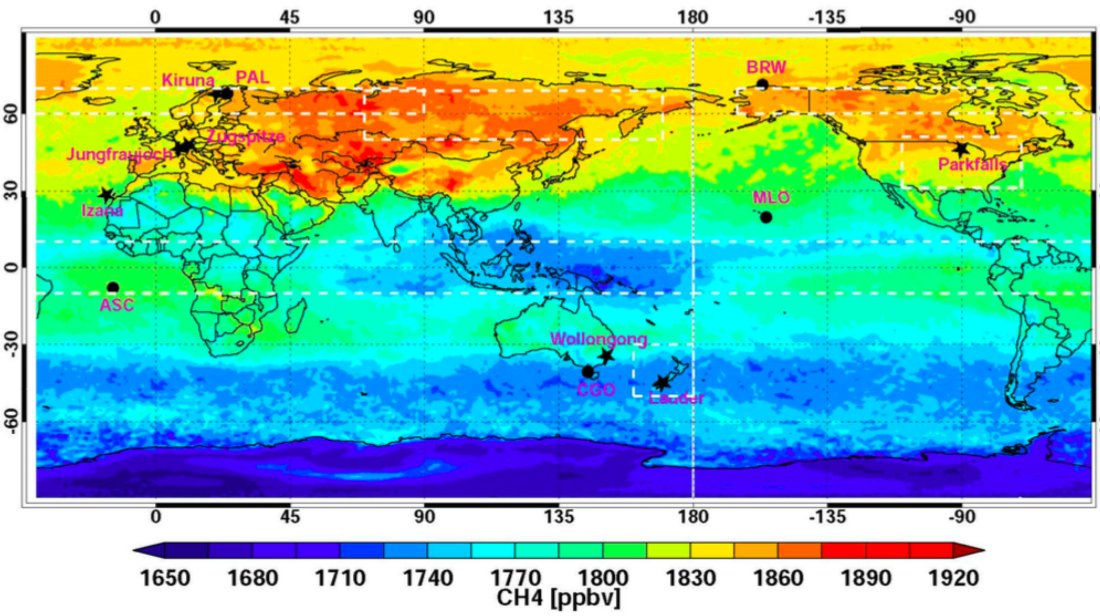

Figure 3.14: Global monthly mean methane at 400 hPa level in July 2017. [51]

AIRS is is a cross-track scanning instrument, and has 2378 channels covering 649–1136, 1217–1613, and 2169–2674 cm$^{(}-1)$ at high spectral resolution. The heart of the instrument is a cooled (155 K) array grating spectrometer operating over the entire AIRS infrared (IR) spectral range at a spectral resolution of 1200. The concept requires no moving parts for spectral encoding and provides 2378 spectral samples, all measured simultaneously in time and space.

The term "sounder" in the instrument's name refers to the fact that temperature and water vapor are measured as functions of height. [51]

IASI

EUMETSAT Polar System is a satellite programme consisting of a series of three operational meteorological satellites, named Metop (Meteorological operational satellite) A, B and C. ESA is responsible of the development of the space segment whilst EUMETSAT is responsible of the mission requirements. [52]

The main purpose of this satellite programme is to study operational meteorology however it is also focused on the contribution to ocean and ice monitoring, climate monitoring, atmospheric chemistry and space weather.

The Metops' launches were on the 16th of October of 2006, 17th of September of 2012 and the last was on the 7th of November of 2018. The improvements from one to another were less weight at launch (4087, 4085 and 3950 kilograms, from older to newer) and more power. [53] [54] [55]

Figure 3.15: Render of Metop-A [56]

All of the three satellites include the Infrared Atmospheric Sounding Interferometer (IASI) which has remained the same with every newer satellite. It measures an infrared spectrometer that has a horizontal resolution of 12 kilometres over a swath width of about 2.200 kilometres.

Ozone, carbon monoxide, methane and nitrogen dioxide columns are also measures by IASI with a horizontal resolution of 25 kilometres and an accuracy of 5% for the first gas, and a resolution of 100 km and 10% accuracy for the others, taking into account cloud-free conditions. [57]

3.4 Market needs

The product that comes up from this project is the methane emission data provided by a nanosatellite. Consequently, the possible costumers that would need this kind of information would be either the methane emitters themselves, or the corresponding regulatory entity.

The key aspect to consider when analysing the target is if the company responsible of the gas emission, loses profits or not because of this emission. In the subsection 3.1.2, it is listed the different methane emitters and one can realise that all the emitters, apart from one, release methane as a collateral consequence of the developed activity.

This distinctive emitter is the oil and natural gas industry, that since methane its a component of the product they are selling, if there are leaks of this gas, there are economic losses.

3.4.1 Potential costumer: Oil and Natural gas industry

As it was explained in the Subsection 3.1.2, methane can be produced as the result of geological procedures that end up forming fossil fuels. Coal, petroleum (or oil) and natural gas are the main fossil fuels used for human activities.

The International Energy Agency (IEA) affirms that the energy sector emitted a quantity of 130 million tonnes of methane emissions during the last year approximately. Although emissions also occur during coal and bio-fuel production and consumption, oil and gas operations are by far the largest source of methane emissions in this sector, emitting 60% of is total emissions.

The detection of methane leaks in the oil and gas industry, can be a cost-effective mitigation option. Since methane can be sold when it is captured, it magnifies the benefit from its detection, not only in terms of cost benefit, but also environmentally. The IAE estimates that around 45% of the 80 million tonnes of methane emissions originated by this industry could be avoided with measures that would have no net cost. [58]

Emissions in oil and gas industry are associated with many different processes in upstream (well development and production), as well as midstream (transportation and storage) oil and gas activities.

In the following figure it is shown a supply chain with the different percentages of emission for each stage of the process:

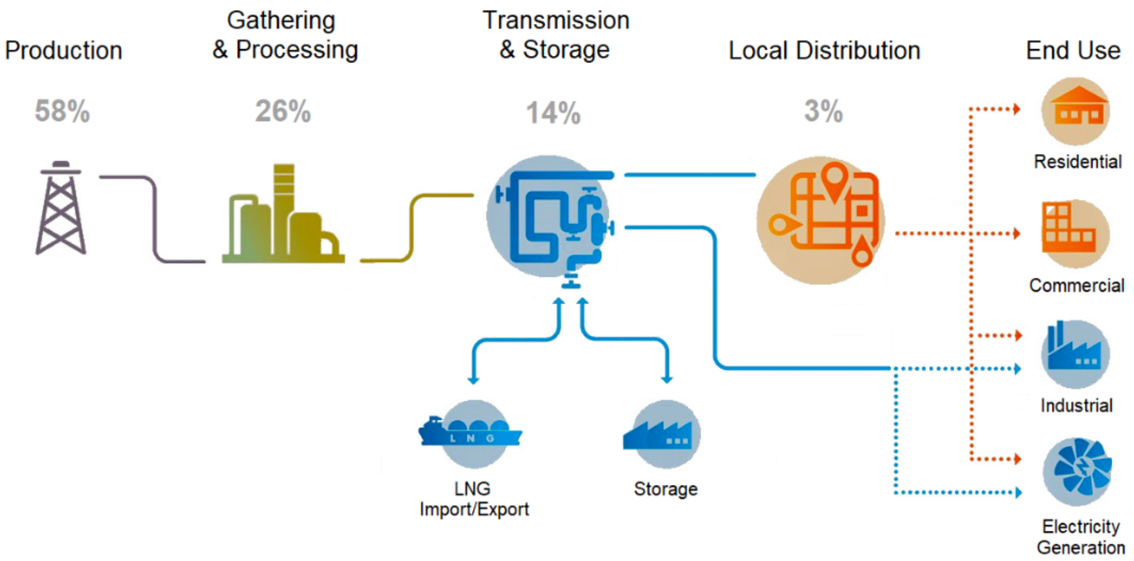

Figure 3.16: Methane emissions from the various components of oil and natural gas supply chain [59]

As it can be seen,the largest source within the sector is the production of the matter, therefore the urgent need of emission reduction must be focused on this. [60]

Fortunately there are several multiple international oil organisations that are starting to develop initiatives in order to reduce their methane emissions:

- The Methane Guiding Principles (MGP) established in 2017 is a multi-stakeholder collaborative platform that incorporate over 20 institutions from industry, intragovernamental organisations, academia and civil society. Their aim is to achieve a methane emissions reduction by developing and implementing methane policy and regulation.

- The Oil and Gas Climate Initiative (OGCI) aims to improve methane data collection and develop and deploy cost-effective methane management technologies. This association is formed by thirteen major international oil and gas companies. In 2018, OGCI members set a goal to reduce the collective average methane intensity of its aggregated upstream gas and oil operations to below 0.25% by 2025, from 0.32% currently.

- The Oil and Gas Methane Partnership (an initiative of the Climate and Clean Air Coalition) provides protocol for companies to survey and address emissions and a platform for them to demonstrate results. It consists of group of ten oil and gas companies, governments, UN Environment, World Bank, and the Environmental Defence Fund (EDF).

3.4.2 Methane regulation

Even though there is an effort to mitigate these large emissions from different entities and organisations, regulations are necessary to establish a level of commitment with the main emitters.

As the development of this project, it is found that some regulatory entities could be potential costumers for the data provided by the satellite proposed. Unfortunately, at the moment there are not many strict regulations about methane emissions worldwide.

Within all the different methane emitters, explained in Subsection 3.1.2, we could differentiate two big groups: the ones which emit as a part of a natural process, and the other ones that are caused by human impact. In the first group we could classify the following emitters: cattle, manure used for agriculture, rice production and other agricultural sources.These emitters should be also regulated, as their impact ends up being more than half of the total emissions, but, for the moment, they are not given the importance they deserve.

This second group involves oil and natural gas industry, landfills, waste water, coal mining, biomass burn and stationary and mobile resources. Since these emissions depend on human activity governments tend to focus their methane regulation plans on these emitters, specially in the regulation of oil and gas industry, at first and following, landfill emission regulation. So for the feasibility of this project, we should take into account regulatory entities.

European Union

Currently the European Commission of Environment does not lay down methane emissions ceilings, but provisions for the gas control and accumulation and migration of landfill gas.
Nevertheless, the Commission adopted last year some regulations for the following years, which should generate a decrease on global methane emission levels in landfill sites. For instance:

- By 2035, Member States can only landfill 10% of their municipal waste.
- By end 2023, Member States shall ensure the separate collection of bio-waste.
- By end 2023, the Commission will consider a food waste reduction target.

The European Union methane emissions are reported to the United Nations Framework Convention on Climate Change (UNFCCC) in the greenhouse gas emission inventory of the member states of the EU, and are available through the European Environment Agency (See Figure 3.17).

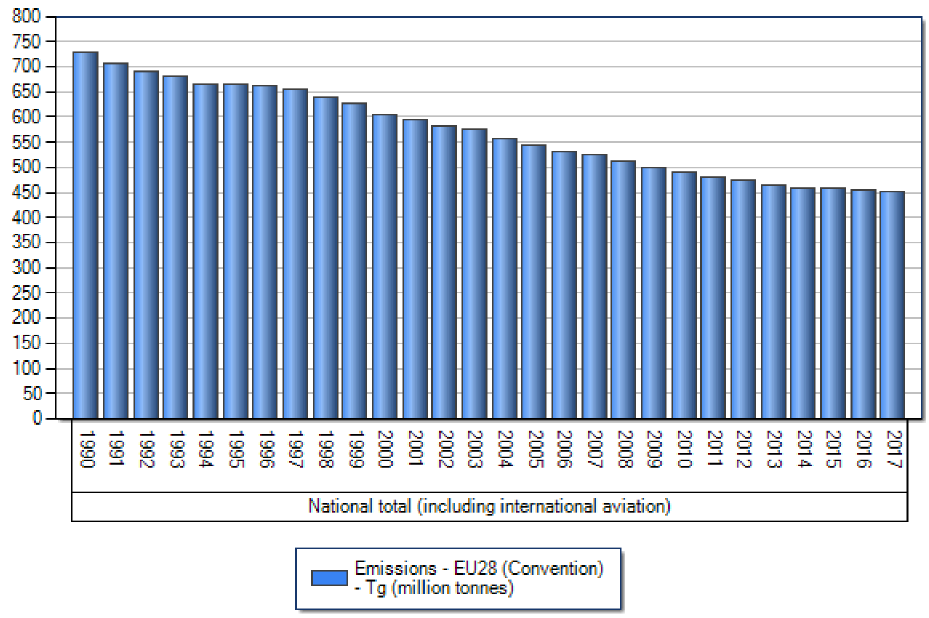

Figure 3.17: EU Member States' methane emissions [61]

The instruments used for the gas emission control of the European Union, are left to the choice of each Member State. There are satellite technologies to provide independent top-down emission estimates of methane emissions at regional or national scale in areas that are sufficiently covered by atmospheric observations. The UK and Switzerland already use top-down estimates based on inverse modelling (and satellite data) of national total methane emissions already (See Annex A.2).

United States

The United States follows the regulation imposed by Environmental Protection Agency (EPA). EPA's federal regulations currently have requirements in place to find and repair fugitive emissions so any facility subject to those requirements would have to be in compliance. At this time, the fugitive emissions requirements are a *"find and repair or replace"* program using optical gas imaging camera or a hand held monitor that monitor at a component by component level at a specific site.(See Annex A.3).

The penalty policy applied for oil and gas wells is more focused on the leakage produced by damaged instruments used for the product extraction. This includes failure to tag leaking equipment for repair or remonitoring, late repairs or no repairs per piece of equipment or equipment standard violations, being the amount of the fine from $ 100 to $ 375,000, if the broken item is not repaired or replaced within the available time. [62]

Moreover, other states like California, Colorado, Ohio, Pennsylvania, Utah and Wyoming, have their own regulation and standards on methane emissions.

Other countries

Canada has introduced regulations to cut methane emissions in 40-45% by 2025 from the 2012 baseline. Their policies will start on the 1st of January 2020, the earliest and in 2023 the latest. These consist in: implementation of Leak Detection and Repair (LDAR) program to stop natural gas leaks, leakage inspection, limited venting production in general terms, from pneumatic devices and from compressors, and the prohibition of venting from well completions involving fracturing. [63]

The European country, non-member of the EU, Norway, also shows an advance in terms of methane regulation. Such as policy instruments to encourage action to reduce N2O and methane emissions from the agricultural sector. Activities for recovering methane from manure pits and landfills and using it for energy purposes, installing recovery systems at landfills where organic material has been deposited. The methane can either be flared or used in energy production. In either case, emissions are reduced. [64]

3.5 Market situation summary

After the research done in the current market situation, it is seen that at the moment there are so many different kind of techniques for the measurement of methane emissions, either terrestrial or spatial. The advantage given by EO via satellites is that a large area can be sampled and it can be determined a focus of emission, whilst with terrestrial instruments it can just be measured if you are located in the exact point asked.

Considering the application of the satellite proposed in this project, the costumer that would be more interested in it is the oil and natural gas industry. Although the companies of this industry might have a long-term benefit, being the import of benefit about 2 billion dollars for instance in the USA, it is not worth for the companies to invest in the project since it just represents less than 1% of annual industry capital expenditure. [65]

This leads to the decision of choosing the corresponding entities that control and regulate their emissions, to be the most potential costumer. Consequently, at the current state of the study, the value-cost model will be focused on regulatory entities. However, a secondary costumer will be considered: the oil and gas companies that want a control over their methane emissions.

4 | Preliminary value-cost model

The objective of this project relies on this chapter. After having analysed the urge of methane detection, plus the competitors and the potential costumers, a preliminary economic study is done.

Value is the perception of a product or service considered by its worth or usefulness. The more valuable something is, the more money is expected to cost.

Cost is the monetary valuation of effort, material, resources, time and utilities consumed, in production and delivery of a good or service.

Therefore, while the cost is something considerably objective, the value is not, and it depends on the costumer's preferences. Hence, a further analysis of the target has to be done.

After that, in the next sections it is described the value proposition and its consequent impacts on the cost, as well as the mission's cost approximated. It has been difficult to develop a preliminary value-cost model due to the lack of missions and type of satellites operating with the same purpose. Then, to reinforce this study, a preliminary business model CANVAS is done, adding the remaining sections.

4.1 Target

As mentioned before in Section 3.5, this value-cost model will be focused on the regulatory entities of Oil and Gas Industry, as it has happened to be the most feasible costumer. Although, on secondary role it is considered that the service can be provided as well to oil and gas companies that want to have a control on their emissions.

4.1.1 Geographic study

As part of the target analysis a geographic study is made, not only to know the provenance of the costumers, but also for the planning to develop an orbit to overview the desired location.

Here below, a list of the top ten world's oil producers is shown, quantified by their million barrels [1]produced per day:

Country	Million barrels per day
United States	17.87
Saudi Arabia	12.42
Russia	11.40
Canada	5.27
China	4.82
Iraq	4.62
Iran	4.47
United Arab Emirates	3.79
Brazil	3.43
Kuwait	2.87
Total top 10	**70.96**

Table 4.1: The 10 largest oil producers in 2018 [66]

Previously explained and shown in Figure 3.16, the activities that emit more methane within Oil and Gas supply chain, are production (58% of the total), gathering and processing (26% of the total) and transmission and storage (14% of the total).

Therefore, this activities have to be taken into consideration geographically for the future design of the satellite's orbit.

The United States will be taken as the model country to analyze as the target for this project, not only because it is the largest oil producer country, but also because it has the stronger regulation and penalty policies on this industry. The corresponding regulatory entity is the US EPA.

[1]Internationally, in the oil industry, an oil barrel is defined as 42 US gallons, or 159 litres approximately.

Following, three maps of the United States are shown with Oil and Gas wells (Figure 4.1), its processing and refining plants (Figure 4.2) and its product terminals and storage location (Figure 4.3):

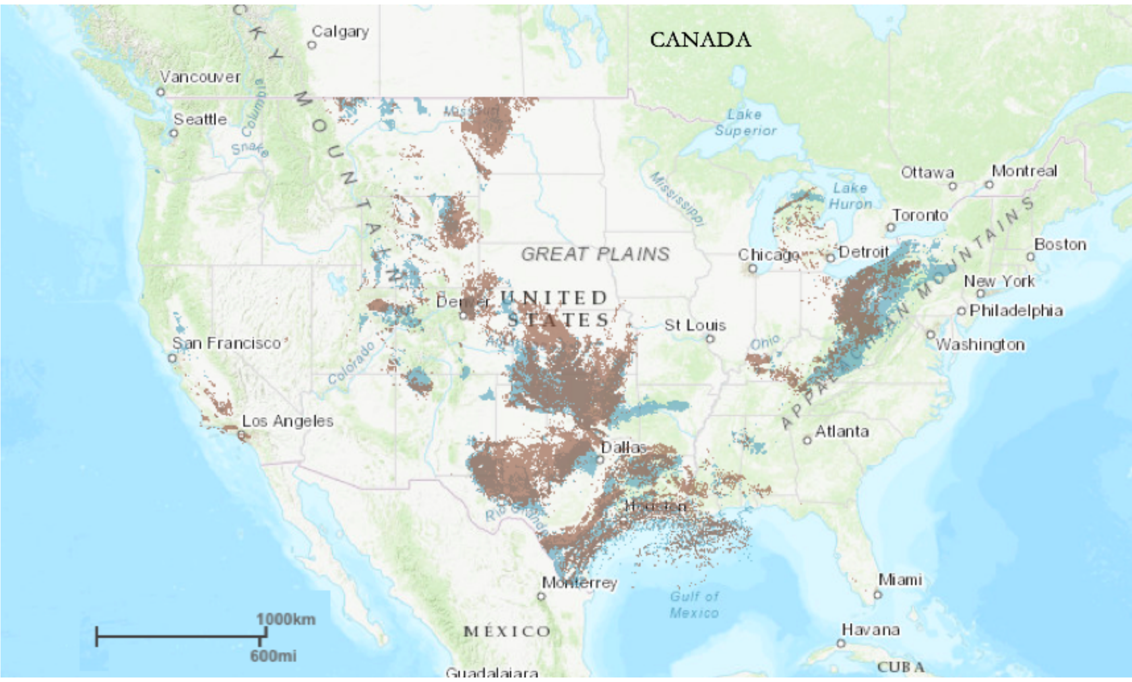

Figure 4.1: Map of the Oil (brown) and Gas (blue) wells in the United States [67]

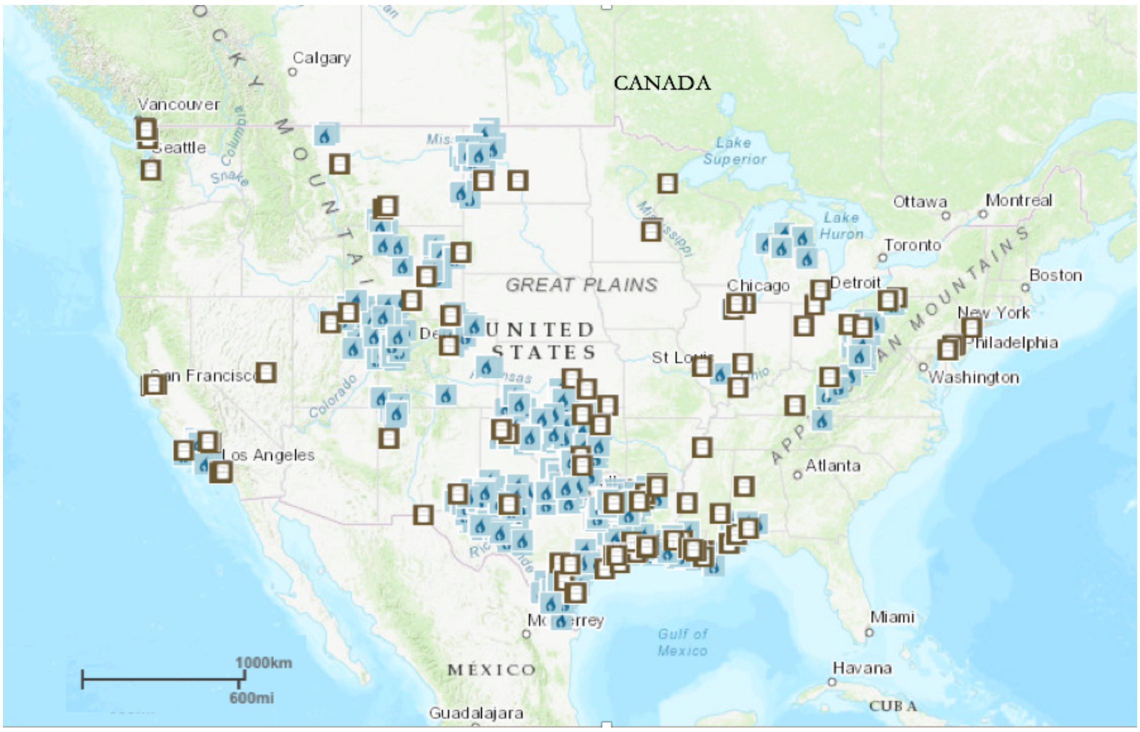

Figure 4.2: Map of the Oil (brown) and Gas (blue) processing and refining plants in the United States [67]

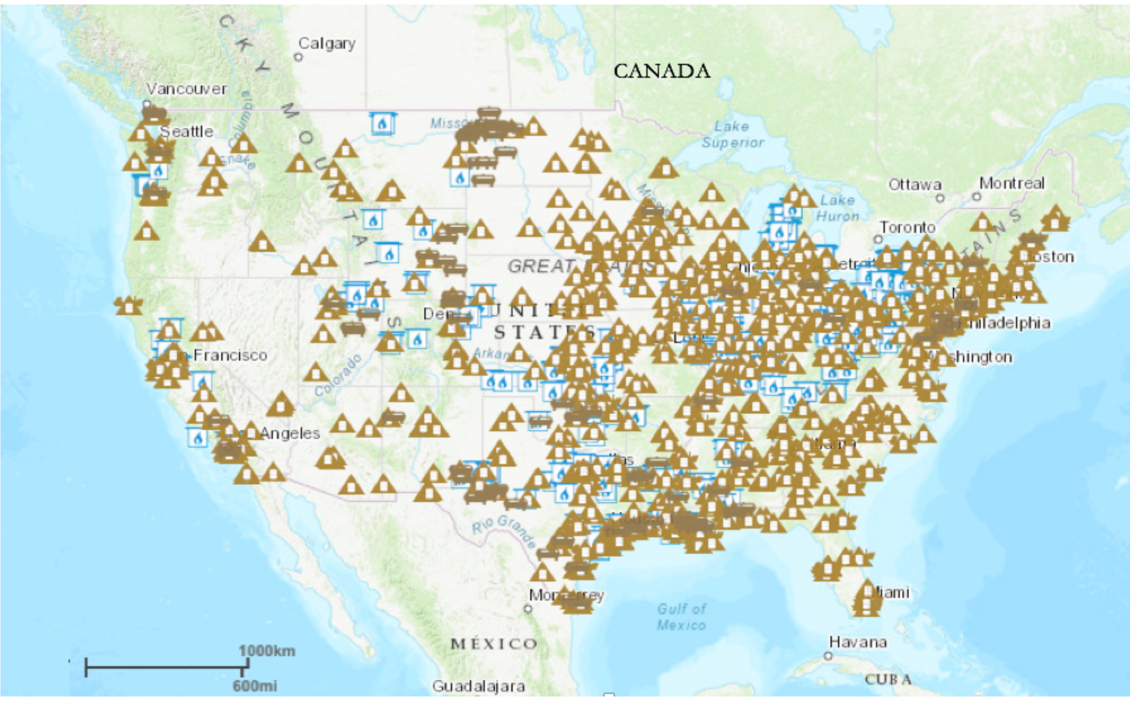

Figure 4.3: Map of the Oil (brown) and Gas (blue) transport and storage terminals in the United States [67]

4.1.2 Behaviour study

Following EPA's Appendix VI, about Leak Detection and Repair Penalty Policy, each Oil and Gas facility is required to list all the instruments used in their wells, or refining plants, as well as the leak detection and monitoring is compulsory for valves, pumps, compressors or other flanges or connectors.

Although this is a regulatory procedure, some companies could report false informs. Even though EPA does routine inspections, the total international outreach may not be always possible.This situation may leave EPA uncertain about its labour. There may be, as well, certain companies that want to have a control over their facilities in order the avoid the corresponding fines.

4.1.3 Target summary

It has been chosen that the main target for this project is the US EPA, because it is the costumer that would be more interested since its country has a vast amount of wells and Oil and Gas processing plants to monitor and control. Hence, it would be of their interest a regular control of all the country methane leakage situation. The enclosure of the target does not benefit the project, therefore, the product is left for other costumers, like oil and gas companies, to be bought.

4.2 Value proposition

The product of this business model is the satellite imagery of methane emissions. The satellite that will grant this data will be a constellation of nanosatellites operating in LEO/VLEO, and will have improved features above other methane data providers.

The image provided will have the aspect as the one seen in Figure 4.4. The costumer will be able to have an specific area monitored during a six-month or one-year period, to be able to detect occasional exceeding missions, moreover, an emission rate control over on area can be requested, using all the local data and applying modelling techniques.

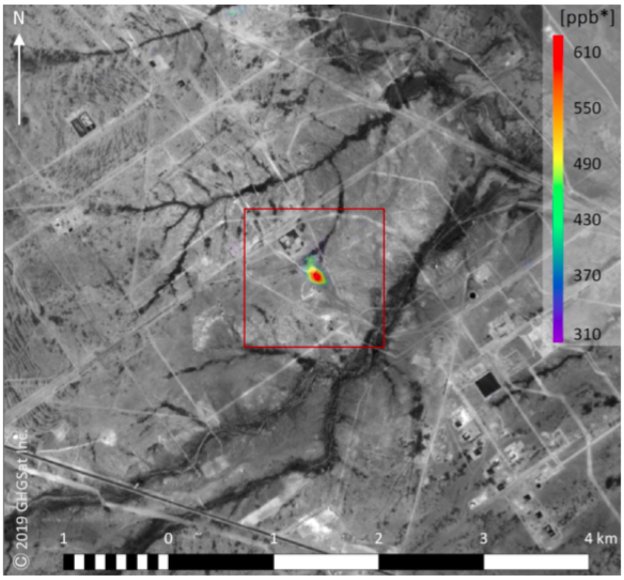

Figure 4.4: GHGSat image of methane emissions [68]

In order to add value to our product in front of other competitors certain requirements have to be followed to attend the costumer's preferences:

- A full coverage of the targeted area.
- Better ground resolution that the competitor's offer.
- A product's price worth its value.

In Table 4.2, it is shown some of the parameters that are affected from the value proposition decided, and their consequent cost impact. They will be further explained in the following section.

Value Proposition	Affected Parameters	Cost Impact
Specified Geographic Coverage	Orbital Parameters	Depending on them, the number of satellites may vary.
	Swath Width	If this value is larger, less number of satellites will be needed.
	Altitude	For a lower orbit altitude, the satellite's lifetime is reduced due to atmospheric effects. Then, for a big constelation satellites have to be replaced with more frequency.
	Number of satellites	The manufacturing cost is multiplied with the number of satellites needed.
Smaller pixel size	Payload's specification	For greater payload's features, the price of it will be higher.
	Altitude	Previously explained.
Lower price compared to competitors	Reduction of size	The manufacturing costs for a small satellite are reduced, but the big economic impact is seen in the launch expenditures.

Table 4.2: Relationship between the value proposition, its corresponding affected parameters and consequent cost impact

4.2.1 Affected parameters by the value proposition

The overview of the affected parameters is split in the three different concepts mentioned as part of the value proposition: the coverage of a requested area, a smaller pixel size and the reduction of price, through the reduction of size.

Coverage of a requested area

The coverage area requested is the conterminous United States, this area has an surface of 8,080,464.3 km^2, from which 7,663,941.7 km^2 is contiguous land, the rest is water area.

The geographic coverage of a certain area of the globe, depends mostly on four other parameters: the orbits parameters (inclination), the payload's FOV, the altitude of the satellite and the number of satellites.

The inclination is the angle between the equator's plane and the axis of direction of the satellite. At the moment, all satellites used for methane monitoring are operating in a Sun Synchronous Orbit (SSO). This type of orbit is nearly polar and has the advantage that the satellite passes over any given point of the planet's surface at the same local solar time, so it can be settled to monitor an area with the appropriate solar light needed. [69]

As SSO are given by a determined inclination according to its altitude, an approximation of it is done by knowing the other satellites' inclination and altitude:

	GOSAT-1	Sentinel-5	GHGSat	GOSAT-2	AQUA	Metops
Altitude [km]	512	666	613	817	705	817
Inclination [deg]	97.5	98	97.8	98.7	98.2	98.7

Table 4.3: Altitude and inclination of the current satellites operating in EO for methane detection

The resulting graph and trend line with this data is the one shown in Figure 4.5.

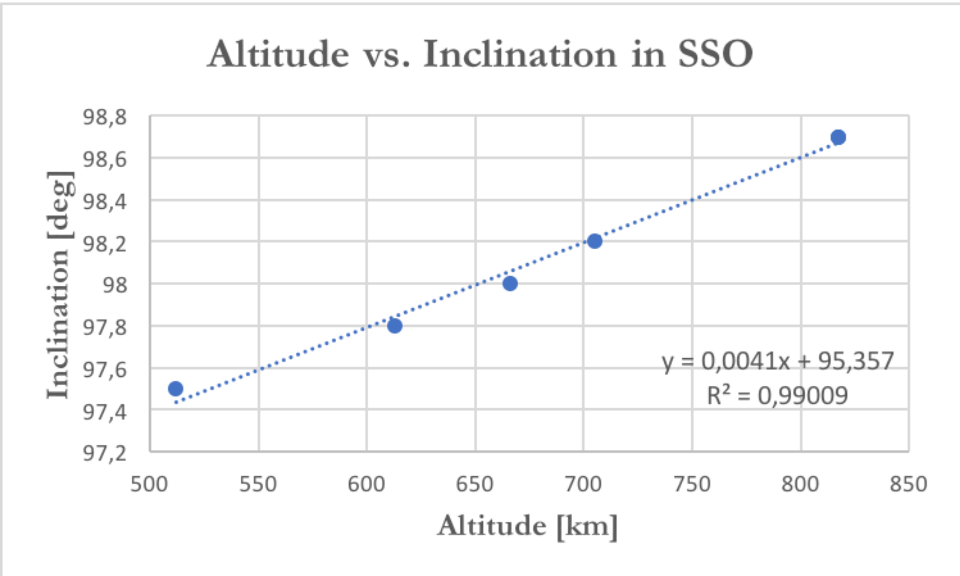

Figure 4.5: Altitude vs. Inclination of methane detection satellites in SSO

Following this trend line, for a satellite operating, for instance, at 400 km of altitude, the inclination needed for a SSO would be 97°.

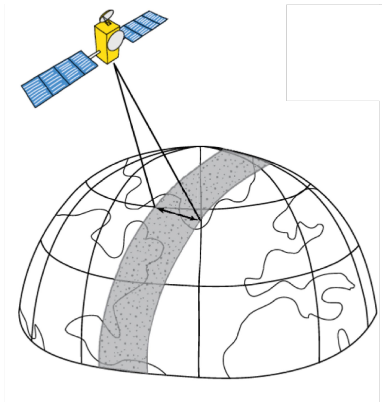

Figure 4.6: Swath of a satellite [70]

As the satellite orbits around the Earth, the sensor "sees" a certain portion of the Earth's surface. This portion is called the swath of the satellite. This area depends on the payload's field of view and the satellite's altitude.

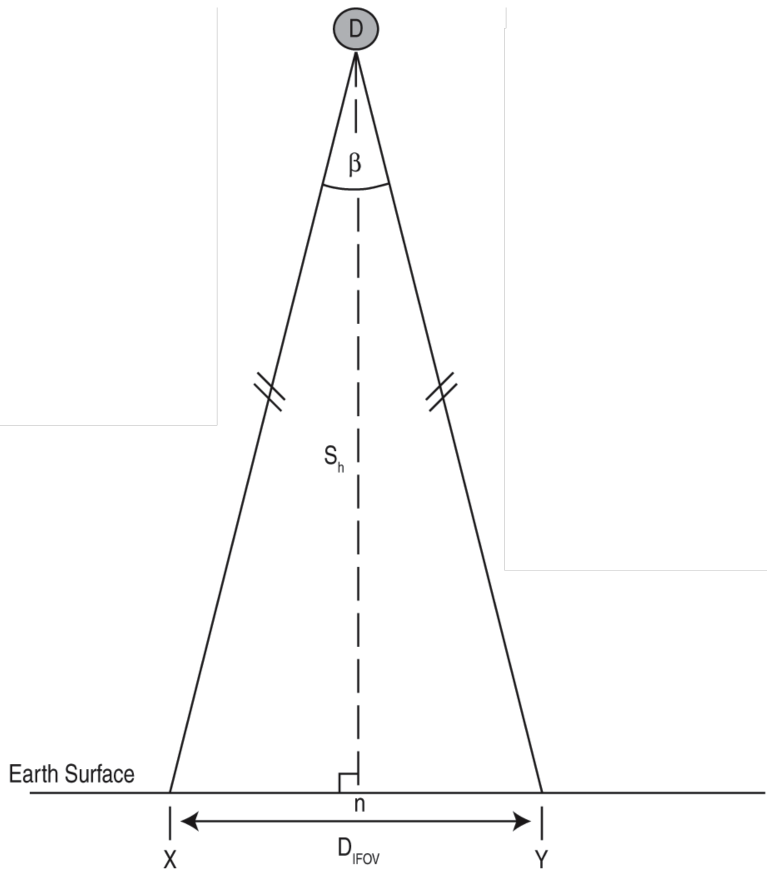

Figure 4.7: Triangle explaining the relationship between swath width, FOV and altitude [71]

Figure 4.7, represents an explanation of the correlation between the payload's FOV (β), the satellite's height (S_h) and the resulting swath width, ground field of view or the diameter on ground of the IFOV (D_{IFOV}). This can easily be explained through trigonometry:

$$D_{IFOV} = 2 \cdot tan(\frac{\beta}{2}) \cdot S_h \tag{4.1}$$

So we can assume, that the lower the satellite orbits, the more narrow the swath width will be. For instance, as a preliminary value, for a spectrometer with β=0.30° and an altitude of 400 km, the resulting swath width is 2,1 km.

Once the swath width and the inclination are determined, the number of satellites can be estimated. To do so, several approximations have been considered:

- The contiguous US area has been approximated to a rectangle, taking the length reference of the distance between Washington's coast and Maine's coast, that is 4,200 km. (This distance has been taken because it happens to the largest from other distances coast to coast, like from California's coast to Florida's coast there are 3,600 km.
- It has been chosen that the altitude for the satellite in this study case is 400 km. This leads to an inclination of 97°, than will be approximated to 90°, for this calculation. And an orbit period of 1.54 hours (See Table 4.4)
- The linear velocity of the whole area has been estimated to be the same as Portland's (linear velocity. Calculated with the Earth's angular velocity (ω_{Earth}), the Earth's radius (R_{Earth}) and Portland's latitude ($\phi_{Portland}$).

$$V_{Portland} = \omega_{Earth} \cdot R_{Earth} \cdot cos(\phi_{Portland}) \tag{4.2}$$

Height [km]	Velocity [km/s]	Period [min]	Mean Motion [revs/day]
200	7.79	88.40	16.30
300	7.73	90.40	15.93
400	7.67	92.40	15.58
500	7.62	94.50	15.24
600	7.56	96.50	14.92
700	7.51	98.60	14.60
800	7.46	100.70	14.30
900	7.40	102.80	14.00
1000	7.35	105.00	13.72
1100	7.30	107.10	13.44
1200	7.26	109.30	13.18
1300	7.21	111.40	12.92
1400	7.16	113.60	12.67
1500	7.12	115.80	12.43

Table 4.4: Orbital parameters for LEO [72]

The resulting linear velocity is 1,206.26 km/h, this value multiplied by the orbit's period (1.54 h) results in 1,857.64 km that the Earth has rotated when the satellite arrives again to the same point.

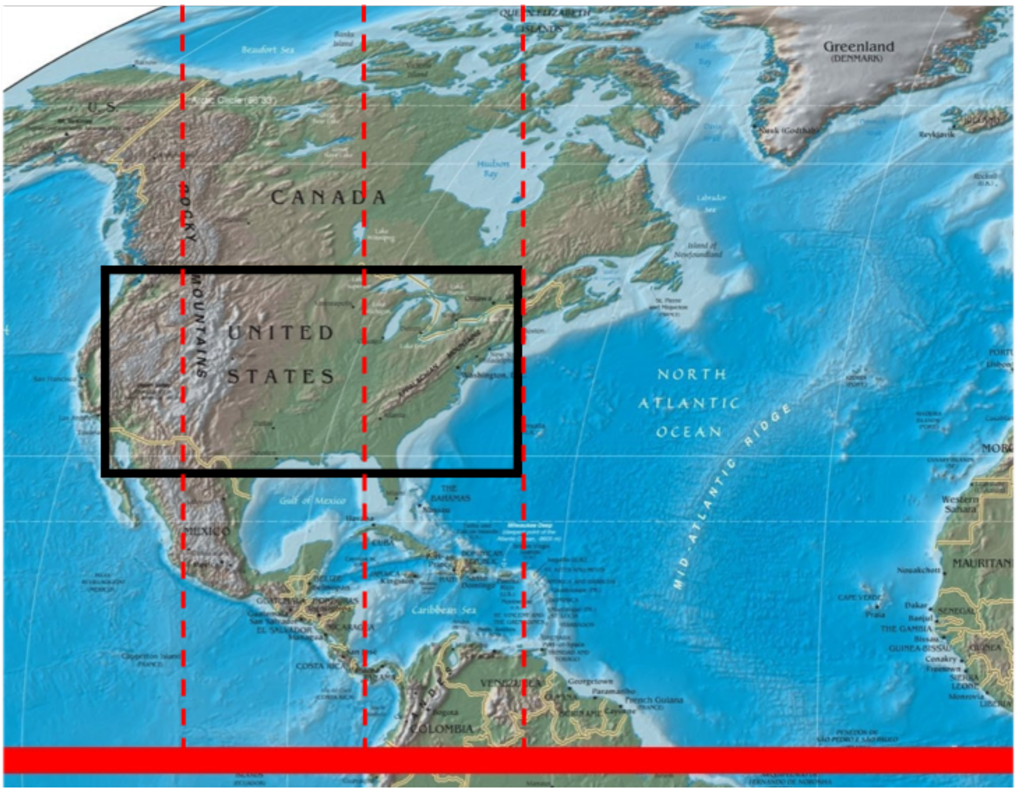

Figure 4.8: Graphic of the approximation proposed for the number of satellites calculation [73]

If we divide the length of this rectangle approximation (4.200 km) and the length that the Earth moves within one orbit, it results in 2,26. This value means that the satellite can go over the targeted area maximum three times. (See Figure 4.8)

Taking into account that the SSO makes the satellite orbit achieve one point at a certain solar time, the satellites required would be around 900, in order to cover the space between the two orbit paths.

This option is rejected because it leads to a huge economic impact, in order to provide the full conterminous US coverage. A higher altitude, for instance 500 km, would provide a larger swath width, and less number of satellites would be needed. However, a higher altitude leads to a slower velocity and larger time period (See Figure 4.9) , in which the linear distance that the Earth will have moved will be larger as well. So maybe less satellites are needed but in similar magnitude.

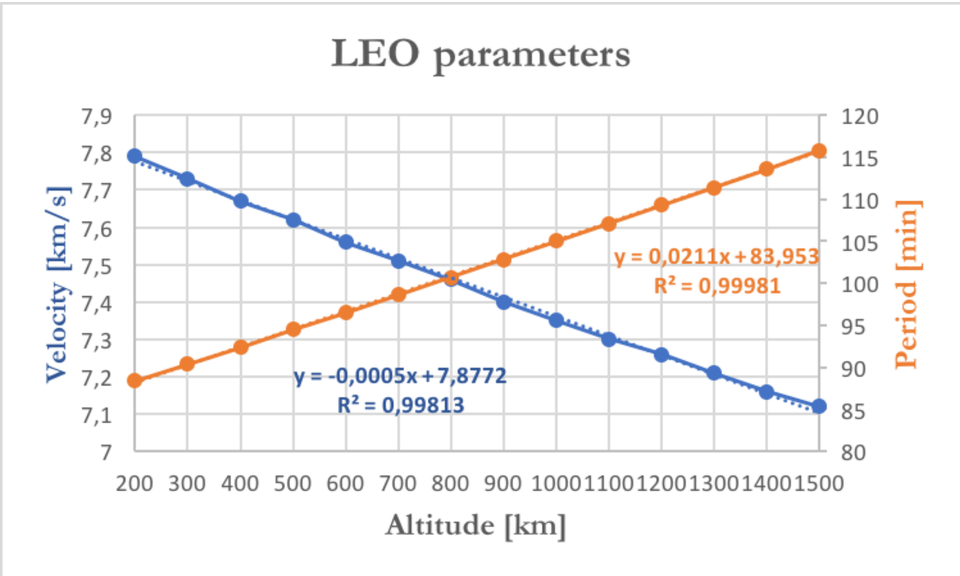

Figure 4.9: Graphic of LEO parameters (Data taken from Table 4.4)

Concluding, an considerable option is to change the parameter orbits, changing the inclination and consequently, not having a SSO. Even though, the altitude can be higher as well in order to provide a larger swath width and a longer lifespan, of about an approximated value of 500 km.

Greater spatial resolution

The spatial resolution is a parameter that depends on the payload's specifications. Although, it is true that the maximum pixel size coincides with the swath width.

Using the Equation 4.1, taking a FOV(β) [2]=0.30 and an orbit's altitude of 500 km (as it has been previously decided that the satellite will have an altitude higher than 400 km), the resulting swath width, and hence, maximum pixel size of 2.62 km^2, which is lower than the other pixel sizes of the other satellites working in methane detection.

	Competitors' pixel size [km^2]					
Proposed pixel size [km^2]	GOSAT-1	Sentinel-5	GHGSat	GOSAT-2	AQUA	Metops
2.62	10	7	10	10	45	12

Table 4.5: Comparison of the proposed satellite's maximum pixel and the competitors'

For this payload's FOV, if the altitude is increased the corresponding maximum pixel size is still small compared to the other satellites working in methane detection. For an altitude of 500 km is 2.62 km^2, as previously said, and is 4.71 km^2 for an altitude of 900 km.

Reduction of size

The reduction of size leads, obviously, to a decrease in the cost of the satellite manufacturing, and most importantly of the launch cost (See Table 2.2). Hence, the image provided can be cheaper.

In comparison with the other satellites, the one proposed will be lighter, so this is the most important advantage above other companies.

	Competitors' satelites weight [kg]					
Proposed satellite [kg]	GOSAT-1	Sentinel-5	GHGSat	GOSAT-2	AQUA	Metops
1 - 10	1750	980	15	1700	3117	4000

Table 4.6: Comparison of proposed satellite's mass and the competitors'

[2]The FOV taken corresponds to a IR Spectrometer suitable for a 3U Cubesat. [74]

It can be seen, that in this quality, the main threat, as it is the smaller satellite is the GHGSat.

Not only, the reduction of size, but also the usual specified objective of the mission, as well as, other features shown in Table 4.7 make a small satellite mission more profitable.

Characteristic	**Cost Related Observation**
Physical	
Light (Mass)	Reduced spacecraft cost
Small (Volume)	Simplified engineering systems
Functional	
Specialized design	Reduce interface requirement and complexity
Dedicated mission	Fewer users and shorter lifetime
Procedural	
Short project schedule	Focused design effort and minimized optimization
Streamlined organization	Less management structure
Developmental	
Existing components/facilities	No development of new parts or technologies
Software advances	Extensive software reuse
Risk acceptance	
Low to moderate mission value	Rely on existing technology
Higher tolerance for mission risk	Reduced redundancy and complexity
Launch	
Small vehicle or piggyback	Avoid launch date slips, stand-downs
Ground Station	
Simplified and autonomous	Need fewer personnel

Table 4.7: Cost related observation according to the satellite's characteristics [75]

4.3 Channels

Channels, in business modelling, are the resources or mechanisms that the company uses to get their value proposition known by their costumers.

There are different types of channel, and from all of them there are two distinguished groups: [76]

- **Direct channels:** Producer and final user deal directly with each other.
- **Indirect channels:** There are intermediaries between producers and consumers.

In the case of study of this project, the costumers are a specified reduced target, US EPA mainly, and then oil and gas companies. Thereupon, the way to get known is basically, going directly to meet your costumer and expose the project in order to develop an economic proposal.

On one hand, with regard to get EPA to know the project, a direct meeting should be arranged as well as a presentation of the project in EPA International Decontamination Research and Development Conference, could be considered.

On the other hand, for the oil companies to get to know us, a good start would be similar to the EPA's approach, trying to have the opportunity to go to the OGCI's annual congress or the annual World Gas Conference, where different oil and gas companies meet. Once there, an exposure of the project could be done.

4.4 Costumer relationship

This section refers to how the company gets their costumers engaged with it, and develop a relationship in which the objective is to obtain a benefit from both sides.

In this study case, the costumer relationship has to be consistent, due to the lack of a lot of costumers. Then it is important to provide the costumer the product within their needs and specified times.

One of the ways, to take care of our costumers is to provide them urgent emission maps when required. The whole mapping will be done every week, but if the costumer requires so, he can get an urgent emission map on demand within three days.

4.5 Revenue stream

The revenue stream is referred to the willingness to pay for the product of service given. It can be different depending on the type of product or service given. In this case of study, an overview of the two costumers' willingness to pay is seen and the current satellite imagery pricing.

4.5.1 Willingness to pay

As the main costumer of this project is a public entity, the urge for them to solve the gas leak situation is pushed for society's welfare.
People who live near oil and gas operations are at an increased risk of exposure to contaminated ground water and air pollution. Then, EDF is seeking for broad clean air protections, in order to get EPA to apply them. [77]

EPA is increasing the enforcement program to harder enforcement actions to address the most egregious cases. In the Fiscal Year [3] of 2017, environmental criminals were required to pay a total of $ 2.98 billion in fines, restitution, and mitigation and were sentenced to serve over 150 years in jail. EPA is finding ways to maximize the effectiveness of its civil enforcement actions and that has resulted in requirements for companies to invest in nearly $ 20 billion in actions and equipment to control pollution. [78]

[3] A fiscal year is a one-year period used by governments to account and budget purposes, it varies between countries. In the US, this period starts in October.

So since, EPA as a regulatory entity just wants to achieve the maximum accuracy in the methane emission control, the willingness to pay is not an issue. Moreover, the fact that every year EPA makes companies invest in their monitoring equipment, a considerable option would be to encourage the companies to hire this satellite monitoring systems. Of course, the first interested in space-monitoring is EPA itself, to have a control over the truth of the oil and gas companies regulatory informs and detect overlimit emissions in advance to avoid worsening air quality.

On the other hand, as mentioned, for those companies that would like to have this space monitoring over their facility, their willingness to pay depends if are specified in oil or gas extraction. For gas extraction the gas leak control is controlled extensively, so an extra monitoring may not be of their interest. But the oil extraction companies don't have a full control over the gas leaks, because its not their selling product. Then, satellite leak monitoring would be of their interest in order to avoid EPA's fines, that can go from a couple of thousand dollars, to a billion in the worst case.

4.5.2 Current Satellite Imagery Pricing

The type of image for gas monitoring is a panchromatic sharpening image, or abbreviated pan-sharpened image. Taking into account that the spectral range in order to retrieve methane has to include 1.6 μm of wavelength (See Subsection 3.4), these are the actual high resolution (HR) satellite imagery prices for this specific satellite purpose:

	HR Archive	**HR New Tasking**	**HR Stereo Archive**	**HR New Tasking Stereo Pricing**
3-Band Pan-Sharpened	\$ 17.50	\$ 27.50	\$ 35	\$ 55
4-Band Pan-Sharpened	\$ 17.50	\$ 27.50	\$ 35	\$ 55

Table 4.8: Satellite imagery pricing for pan-sharpened images per km^2. [79]

There is no requirement for a third or fourth band, as methane does only have two spectral bands, this are reference standard pricing and both of this images are acceptable. The stereo imagery can be a option but it is not a strict requirement, this imagery enables users to generate their own digital elevation models, create 3D visualisations, and accurately extract features. From the two options of just archiving the imagery or selecting areas and times where the data wants to be retrieved: new tasking, it is considerably better to do just the second option to avoid an extracharge.

Although, the proposed monitored area was the conterminous US surface, EPA or the interested companies, could decide to just monitor a smaller area where the oil wells are more abundant. (See Figure 4.1).

4.6 Key activities

To develop the resulting product, several activities need to be done. These are exposed in the following scheme:

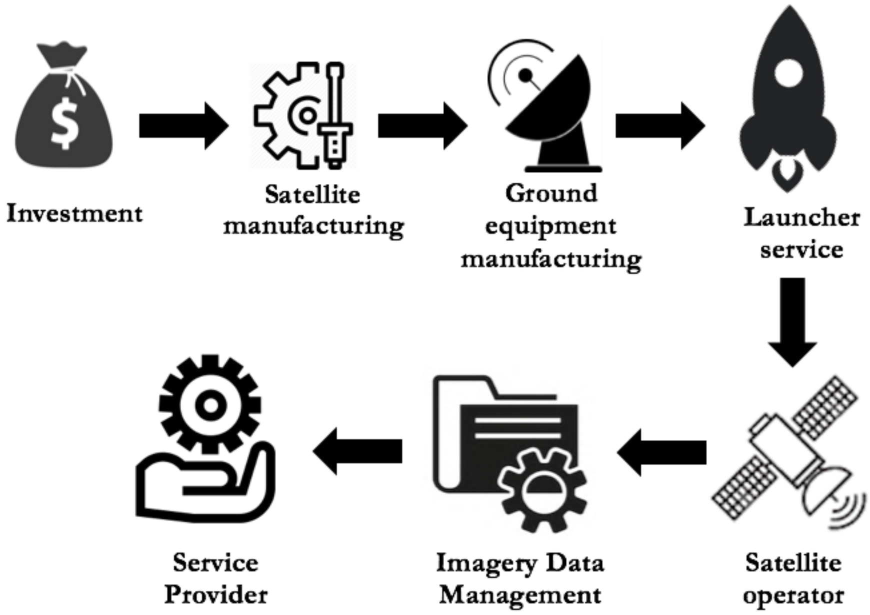

Figure 4.10: Key activities for a satellite mission [80]

From the activities shown in Figure 4.10, there will be some that will be executed by subcontracted companies:

- The satellite will be manufactured by a corresponding manufacturing company.
- To avoid the costs of beginning a brand new ground station, having to find space, the equipment needed, personnel,etc. A ground station will be rented by the project to recollect all the data provided by the satellite.
- The launching will be done by another subcontracted company.

The remaining activities will be done by our company:

- The initial investment.
- The operational procedure of the satellite will be ran by the company as well.
- The imagery data management, once received from the previous recollecting step done by the ground station.
- The manipulation of the product or service itself, and the corresponding selling procedure.

4.7 Key resources

In order to create the product and carry out the project there are certain resources needed. The following list enumerates the resources needed for the completion of the project, from the very begining of the project until its completion:

1. Engineers to assess the project's needs. From the selection process for all the satellite's features to the corresponding instruments needed, the development of the orbit, and all the other requirements for the feasibility of the project, in order to present a proposal for the investors.

2. Investors that economically support the project.

3. Manufacturers and providers are required for the construction of the satellite, and their reputation will add value to our product.

4. A launch vehicle, provided by a launching company to put the satellite into orbit.

5. A ground station to collect all the data downlinked from the satellite.

6. A facility to set the working office.

7. Personnel responsible for the data modelling and producing the subsequent concentration maps.

Once all this resources are found and taken into account, the project can proceed.

4.8 Key partners

Since the main costumer of this service is the regulatory entity that penalize the excessive methane leakage from the oil and gas wells, the key partner that must be there if the project advances is the entities that propose, develop and impose the corresponding law.

Taking the US as the model example, the procedure of regulation is explained. First of all, the Congress proposes a bill [4], then if it is approved by both houses of the Congress and afterwards and by the president, it becomes an act or statute. In our case of study would be the Clean Air Act. Once the act is passed the House of Representatives standardizes the text of the law and publishes it in the United States Code (U.S.C).

[4]A bill is a document that, if approved, will become a law.

Then the corresponding regulatory entities set the requirements about what is legal or not. In our case this is ran by EPA, to verify the Air Enforcement. [81] This key partner is suitable for both costumer cases. Since both of them are related and depend a little bit one on another. The key partner for both cases is the United State Congress.

4.9 Cost structure

In order to develop the preliminary value-cost model the key system elements of a mission will be exposed, to evaluate them independently afterwards and attribute them their perspective costs.

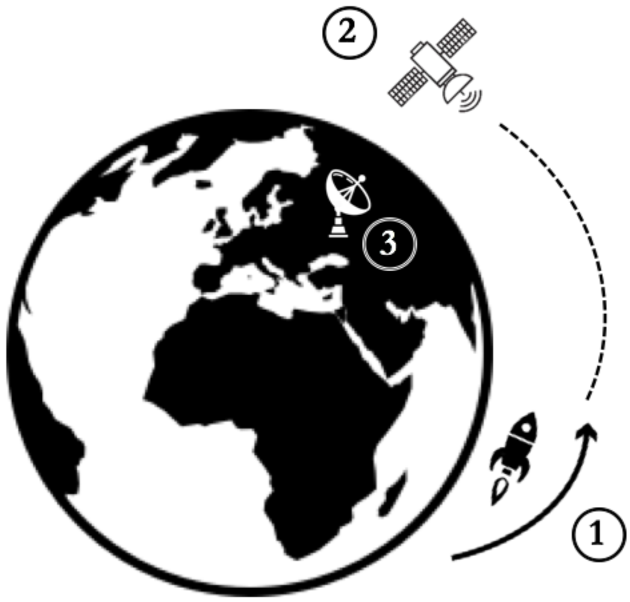

Figure 4.11: Scheme of the key system elements for a satellite mission

As it is shown in Figure 4.11, the first aspect to take into consideration for the value-cost model is the cost of the satellite's launch, the satellite itself and the ground station needed to receive the data downlinked[5].The corresponding human resources cost for the development of the project, imagery manipulation, and selling procedure are disregarded in this section.

[5]Downlink is sending data signals from a satellite to ground stations.

4.9.1 Launch cost

The reduction of the satellite size, involves a reduction in its manufacturing, since standards components and commercially available bus designs are available, the impact of the launch cost its significantly higher compared to the total mission budget.

At the moment, the options for small satellite launching are: [82]

- **Dedicated launch**: an specific launch only for the user. This shows a clear advantage, the destination orbit of the payload can be chosen to best fit the mission, as well as the date of launch. These type of launches are usually developed for educational institutions, as the cost of it is far in excess of an standard mission budget.
- **Rideshare** : this launches are a type of multiple-manifested launch where a number of similarly sized payloads share a single vehicle launcher to a common agreeable orbit. This reduces the launch cost for each satellite, but also it has a particular drawback, that is adjusting to the manifestation of all the payloads preferences, such the launch date or the orbit altitude, inclination,etc.
- **Piggyback launch**: being the secondary payload of the launch of a satellite. The destination orbit and launch schedule is determined by the requirements of the primary payload. So, to be launched by piggyback, the payload has to flexible in its operation in all LEO environments, or wait for the suitable piggyback opportunity.

As it was previously mentioned, the option of a dedicated launch is dismissed because it causes a huge economical impact on the mission's budget. From the remaining options, the rideshare is the best option since all the payloads launch can reach to an agreement, whilst when being launched by piggyback there is less freedom of choice.

The prices for a small satellite launch vary from \$ 7,100 per kilogram, like in the case of the Indian Space Research Organisation (ISRO) satellite PSLV-CA, or rise up to \$ 125k per kilogram in the case of some Spaceflight launches.

In Table 4.9, some launch vehicles are shown, with its respective specific cost of launch per kilogram. These launches have a larger capacity to accommodate small satellites, but they have their orbit altitude and inclination already chosen.

Instead, launch vehicles shown in 4.10, show a greater flexibility in orbit parameters since they don't have them specified, it is an agreeable choice between the companies launching their satellites. Hence, it would be more interesting to operate with one of these launchers.

Vehicle	**Reference Payload [kg]**	**Reference Altitude [kg]**	**Reference Inclination [deg]**	**Approx. Cost [USD]**	**Specific Cost [USD/kg]**
Shtil-1	80	500	79	2.1M	26,300
Shtil-2.1	150	500	79	4.5M	30,000
Shavit (LK-A)	350	420	143	Unknown	-
Shavit-1 (LK-1)	350	700	90	Unknown	-
Pegasus XL	443	200	90	25M	45,100
Minotaur I	580	185	28.5	20M	34,500
Star-1	632	200	52	9M	14,200
Athena Ic	700	200	28.5	20M	28,600
Shavit-2 (LK-2)	800	700	90	Unknown	-
Falcon 1e	1000	185	20	10.9M	10,900
Taurus (2110)	1000	500	28.5	35M	35,000
Kosmos 3M	1500	250	51.6	12M	8,000
Vega	1500	700	90	35M	23,300
Athena IIc	1540	200	28.5	30M	19,500
Minotaur IV	1720	184	28.5	50M	29,100
PSLV-CA	2100	200	28.5	15M	7,100
Rockot	2140	200	63.2	20M	9,300

Table 4.9: Small launch vehicles [82]

Launch Vehicle/ Provide	**Mass/Form**	**Approx. Cost [USD]**	**Specific Cost [USD/kg]**
Lockheed Martin	110 kg	12.5M	113,600
Athena IIc	3U P-POD	300k	60,000
SpaceX Falcon 9	3U P-POD	200k-325k	40,000-65,000
	ESPA Class (180 kg)	4M-5M	22,000-27,800
Spaceflight Services (Falcon 9, ULA EEL V, Antares, PSLV)	1U CubeSat	125k	125,000
	3U CubeSat	325k	65,000
	180kg microsatellite	4.95M	27,500
	300 kg microsatellite	6.95M	23,200

Table 4.10: Available rideshare and piggyback launch prices [82]

4.9.2 Satellite's cost

The satellite cost can vary within different specifications, sizes, precision,etc. Here below, there is the pricing of the different parts of a satellite taking as reference the prices in *CubeSatShop*: [83]

- **Satellite frame**: ISIS CubeSat structures are developed as generic, modular satellite structures based upon the CubeSat standard. The prices for a 3-Unit CubeSat structure oscillate between $ 4,000 and $ 4,500.

- **Attitude control system**: average altitude sensors and actuators can cost from $ 5,000 to $ 10,000. However, it should be estimated that the cost for this system will be more expensive as the pointing accuracy needed is high.

- **Transmission system** needed on board to downlink and uplink the recollected data, depend on the downlink speed. Average prices for this system are between $ 7,000 and $ 9,300.

- **Antenna system**: for instance, ISIS', provide optimal transmission quality and system reliability at minimal volume. The price range goes from $ 5,000 to $ 6,000. As the other components, there are sophisticated antenna systems that can rise up to $ 11,000.

- **Solar cells**: these power source systems oscillate between $ 3,000 and $ 9,300.

- **SWIR Instrument**: this sensor is needed for the application of the satellite's purpose: methane detection, and its price range goes from $ 24,000 and $ 60,000 approximately.

The total construction price for the 3U - CubeSat, taking the lower prices is around $ 75,000. Although in this estimation, there are miscellaneous components that have been not counted. In order to get a better approximation, taking into account the error, it will be estimated a manufacturing cost of $ 90,000.

Payload requirements: SWIR Instrument

It has been decided that the suitable payload for the nanosatellite developed for the project are:

- It has to be a SWIR instrument instead of TIR, because it shows better sensitivity to altitude. (See Subsection 3.3.2)

- The spectral range needed has to include the wavelength value of 1.65 μm, not requiring the 2.3 μm since in this band solar radiation is three times weaker.

4.9.3 Ground station cost

Renting a ground station currently operating is a common procedure in space industry, there are companies who offer this service for those small companies that want to save the cost of owning or building a new ground station infrastructure.

Taking as an example for exemple, AWS Ground Station from the Amazon Company the pricing per minute of service:

Contact Type	Pricing
Narrowband Reserved	$3 per minute
Wideband Reserved	$10 per minute
Narrowband On-demand	$10 per minute
Wideband On-demand	$22 per minute

Table 4.11: AWS Ground Station pricing per minute [84]

This price is set for one ground station, Amazon has two ground stations, one in Ohio and the other one in Oregon. Both ground stations can be considered for this mission, since the downlink time is pretty small due to the condition of LEO.

The distance needed for ground sensors to communicate with the satellite is within 1000 km radius circular area. Then, for a 500 km altitude (and a velocity of around 7.63 km/s, see Table 4.4), the maximum time that will be orbiting over this circular area is about 4.37 minutes, per ground station.

4.10 Summary

As previously said, the development of a full value-cost model has not been done, because of the lack of same mission purposes with the same type of satellite. Even though, the analysis of the current market reveals that there is a current need to develop better technologies for methane retrieval, and there are resources to develop the project and costumers who would demand it. However, for this project to succeed, more costumers would be required. So until more countries become more strict about methane emissions, this project is limited to the US.

5 Closure

This last chapter completes this thesis' report. First a risk analysis is done, then the environmental impact of the project, the extrapolation of the mission's purpose to another market. Then, an approximated budget of the development of this thesis is done and finally, the conclusions achieved with this work.

5.1 Risk analysis

According to NASA "risk is the potential for performance shortfalls, which may be realized in the future with respect to achieving explicitly established and stated performance requirements." A risk analysis can lead to a better success of the mission by identifying potential failures early, and planning methods to prevent any issues.

Main Step	**Sub-step**
A. Identify Risks	1. Start with the mission concept of operations
	2. Identify root causes
	3. Classify priority of risk
	4. Name responsible party
	5. Rank likelihood and consequence of root cause
	6. Describe the rationale for ranking
	7. Compute mission risk likelihood and consequence values
	8. Plot mission risks on L-C chart
B. Determine mitigation techniques	Choices consist of: 1. Avoid the risk by eliminating the root cause and/or consequence 2. Control the cause or consequence 3. Transfer the risk to a different party or project 4. ASsume the risk and continue in development
C. Closely monitor progress	Plot the mission risk values on an L-C chart at key design milestones to see progress.

Table 5.1: Steps of a Risk Management Plan [85]

Table 5.1, shows the main steps for a risk analysis. First, the risks that the mission could potentially experience are identified, afterwards these are prioritized, so as to recognize which risks need the most attention at one time. Then it is approximated the likelihood and severity for each risk to evaluate its total consequence on the mission's purpose.

Nanosatellite missions are harder to do a risk analysis about, because they don't have previous experience or resources on which to rely. There are different source of mission risk to consider: on one hand, hardware and software risks, like requirements, technical baselines, test and evaluation, modeling and simulation,etc. and on the other hand, programmatic risks, like logistics, concurrency, costs, schedule, budget,etc. [85]

Since this report is focused on the economic feasibility, an overview with the main risks is seen. The risks considered are:

- Failure of the payload to retrieve methane. This is not a severe risk, since the spectral band for it retrieval will not change, and the payload requirements include this wavelength in its spectral range.
- The condition of LEO, can make the downlink time small enough to develop problems with the communication of the satellite. Moreover since it has been avoid a SSO, the revisit time will be longer.
- As the first nanosatellite operating in methane detection the lack of experience in this field may cause an inconvenience in the development of the mission.
- Not covering the area targeted may be a big drawback. The orbit parameters should be studied carefully in order to provide the costumer's requests.
- The mission's budget is the most delicate issue in its development, because in the case of financial failure the mission will have to come to an end.

In Table 5.2 these risks are valued in a 5-point scale with its likelihood to happen and the consequence that it may have to the mission's performance, then a Likelihood-Consequence (L-C) chart is done (See Figure 5.1) to visually see what are the most dangerous risks in order to prevent them.

Risk Category	Call sign	Mission Risk	Likelihood	Consequence
Payload	PAY	Failure to retrieve CH4 correctly	1	4
Spacecraft	SP-1	Being unable to communicate with spacecraft	1.5	4
Personnel	PER	Loss of human knowledge and experience	1.5	3
Spacecraft	SP-2	Inability to cover the targeted area	2	3.5
Cost	COST	Mission cost too overwhelming to continue	3	4

Table 5.2: Mission risk, likelihood to happen and consequence on the mission's performance

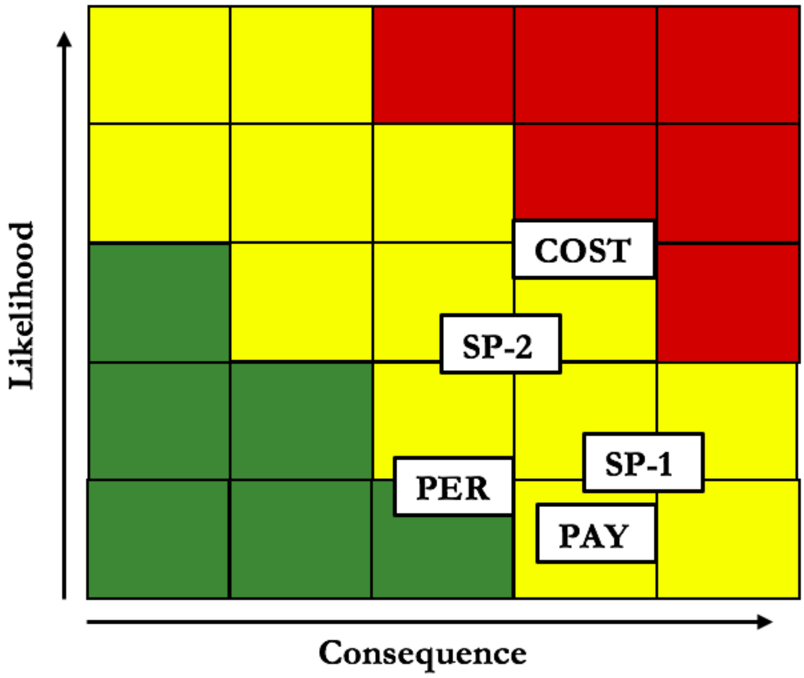

Figure 5.1: Mission risk L-C chart

After identifying the risks, mitigation techniques should be considered if possible. For instance, the risk that has to do with the cost is always taken when starting a project. The other risks may be mitigated with a larger technological study of the mission's needs.

5.2 Environmental study

This project is aimed for an environmental-friendly purpose, being developed for the detection of methane emissions.

EO by satellite remote sensing is a space field within its industry that is becoming more popular, this satellite application can provide a powerful tool for monitoring various features of the Earth's environment.

In this study case, the opportunity to monitor methane from space can lead to determine methane focus that maybe are not contemplated, thanks to the large area from which data can be acquired.

The satellite's presence may not interfere directly in the reduction of these emissions, but if this data is correctly retrieved and used for governmental issues, the impact of this project would reduce the global environmental footprint. Then, these project's impact depends on what would the corresponding entities that receive this information about methane emissions, do for it reduction.

Figure 5.2: Gas flaring [86]

However, this is one of the points of view of the project's mission. There are different opinions about how space missions, without differing of its purpose, cause damage to the space environment.

Currently there is a lack of concern of the effects of satellite launches, and that is an issue to think about. One of the effects that has, is heating of the upper stratosphere and leading to ozone loss, which is caused by the rocket particles detached that absorb sunlight.

Another issue is the space debris left from satellites that are no longer operating. However, LEO satellites are required to reserve enough fuel at the end of their service to enable operators to manoeuvre to a lower orbit which will cause them to re-enter and burn, these burning has not been fully studied and the effects that may have over the atmosphere are not well known, but they might be similar to the ones previously mentioned about the rocket particles. [87]

Figure 5.3: Space debris render [88]

5.3 Extrapolation to other markets

As this project is aimed for the retrieval of one of the greenhouse gases, a considerable extrapolation of the project is retrieving carbon dioxide, for instance.

This greenhouse gas is the largest in the atmosphere, representing more than three quarters of the total GHG emissions. This gas has more regulations, and so there are more instruments monitoring it from space. Actually all the satellites used for methane detection, except for Tropomi on Sentinel-5, monitor carbon dioxide as well.

When a satellite is designed to retrieve methane, it is pretty easy to absorb carbon dioxide with a similar spectral range, from 1.5 μm to 1.7 μm, both gases can be retrieved(See Figure 3.8).

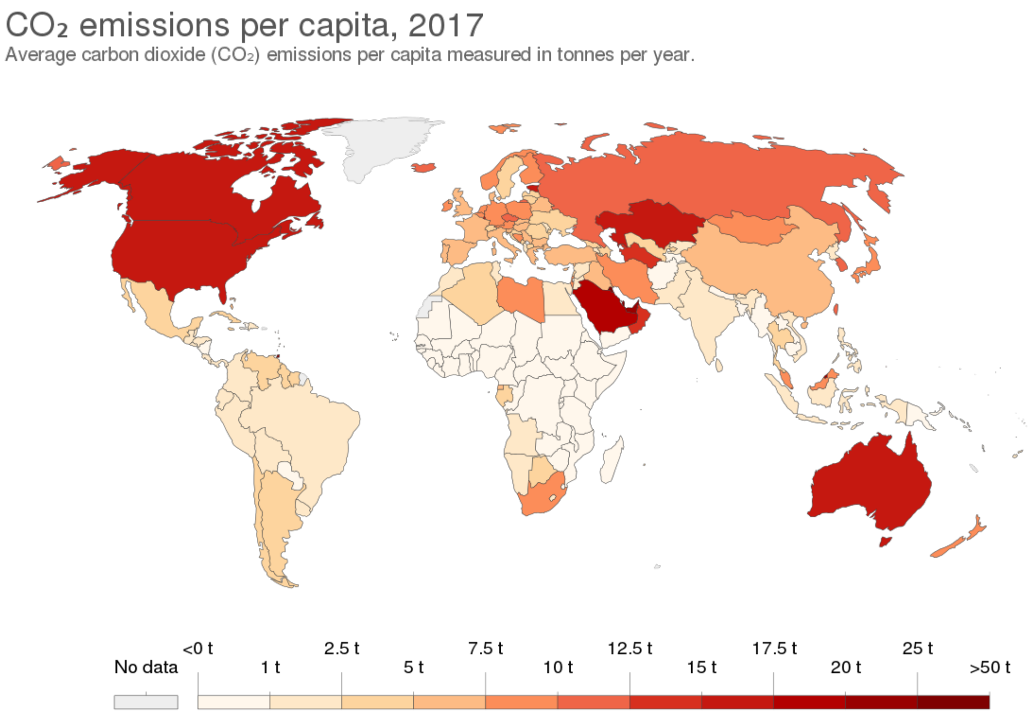

Figure 5.4: Worldwide CO_2 emissions per capita in 2017 [89]

Currently the second country in carbon dioxide emissions is the US, with a yearly amount of 10,877.218 million tones of CO_2, which represents an increase of 453.8% since 1990, and it is the largest emitter per inhabitant. So considering that the proposed satellite has the objective to cover the US, it would be useful as well for both methane and carbon dioxide retrieval. In Figure 5.4, it is shown the world wide emissions per capita in 2017, but the trends are staying similar nowadays. [90]

So summing up: carbon dioxide is the largest GHG, it shares a similar spectral range with methane and also the US its second largest emitter country in the world, so it adjusts perfectly to the mission's features and would be a really interesting to consider this expansion of the business.

5.4 Budget

The budget for this project, just includes the human resources cost for the development of it as no prototype of the satellite has been done, nor any other work. The budget includes the research tasks, economic study development and the remaining tasks to complete this project's report.

Following, in Table 5.3, these are disaggregated:

Task	**Hourly rate (€/h)**	**Time per task (h)**	**Total cost (€)**
Research in small satellites and EO	20	30	600
Research in the greenhouse effect and methane gas	20	45	900
Research in methane detection techniques	20	60	1,200
Research of the current methane detection market situation and choice for a suitable main costumer	20	90	1,800
Information request to various companies	20	20	400
Preliminary value-cost model and business model CANVAS	20	100	2,000
Risk analysis	20	10	200
Study of the environmental impact	20	10	200
Possible extrapolation to other markets	20	10	200
Documentation	20	40	800
Total		**415**	**8,300**

Table 5.3: Budget of this bachelor's thesis

The final cost of the whole bachelor's thesis development has been 8,300 €.

5.5 Conclusions

This project was aimed for a study of the economic feasibility of a nanosatellite operating in LEO or VLEO for methane detection. This study has found out that currently there is just one potential costumer, that is regulatory entities for oil and gas methane leaks. This emitter is just the one that can obtain a benefit by capturing its emissions, not even being the larger one. It is true that most of methane emitters are naturally-caused but, they are in that large amount because of human activity so they should be regulated as well. Global warming is a natural procedure of the Earth, as well as there have been ice age epochs, the problem relies on the humankind eliminating the transforming agents to reestablish the equilibrium and increasing the harmful ones. Even if it is clear that there is an urge of change, most of the governments are just proposing goals of greenhouse gases emission reduction for 2030 or 2050, without enforcing strict laws to really achieve this. So to develop projects like the one proposed, or any other kind of projects aimed for the attenuation of climate change, there have to be government entities that support them.

This study has also shown an obstacle, that has been the lack of a technological study, in order to achieve the completion of a reliable economic study. However, at first stages of the development of a space mission, a market sample has to be analysed to verify that there are clients who would actually buy this service or product. After that first step, as soon as there is an evidence of possible costumers, a parallel study of the technological requirements of the project should be done to verify that the costumer's demands can be fulfilled, within the mission's budget. This obstacle of not having a secondary study, has made more difficult the determination of the feasibility of the project, which at the moment with just one potential costumer seems to be unprofitable. Despite that, with a further economic and technological study it can happen to reveal that it is a cost-effective project and is worth investing in.

A deeper economic study should include a further analysis the costumer's needs, in economic terms, evaluating each US state according to its enforcement laws to check if it would be worth for them to invest in space-based monitoring.

Moreover, as previously said the technological study will have to get through several issues that have not been solved or studied deeply in this report. This includes: the feasibility of an VLEO satellite with the current materials and lifespan approximation of the satellite, the orbit parameters to cover the targeted area, the number of satellites required and its performance to meet the required revisit time. Another technological issue that should be further studied, is to development of payloads able to monitor methane in cloudy conditions as well as in no-land surfaces, for the cases of oil extraction in oceans. Then the payload designed would have better features compared to the competitors and would be a distinguishable satellite from its type.

Once these remaining tasks are done the choice of continuing with the mission's development will be more accurate and will have a lower risk of failure.

A | Annex

A.1 Data queries from companies

For the development of this report, it was required to contact with companies that are involved with the oil and gas industry, in order to ask for their methane detection techniques, if they had a control over their emissions, if they knew about satellite monitoring,etc.

Here below, there is a list with the companies that have been consulted:

- Gas Natural West Africa S.I.
- Sociedad Hidrocarburos Euskadi.
- BNK Sedano Hidrocarburos S.L.
- Compañía Española de Petróleos S.A.U.
- Comisión Nacional de los Mercados y la Competencia (CNMC).
- CORES.
- BP Company.
- Refinería de Petróleos de Escombreras Sociedad Anónima (REPSOL).
- Global Methane Initiative (GMI).
- Environment and Climate Change Canada.
- Environmental Defence Fund (EDF).
- Thoth Technology Inc.
- GHGSat Inc.
- European Comission (Landfill Waste Directive).
- U.S. Environment Protection Agency (EPA).

From all these, just the two last mentioned answered the mail or phone. In the following sections, the information provided by both of them is shown.

A.2 Information given by the European Direct Contact Centre

As a part of my research I contacted the European Direct Contact Centre. After the first mail introducing myself, I was allowed to ask five questions. Herebelow, it is shown the answers that the EU gave me.

1. Are landfills currently fined for exceeding a certain amount of emissions, or is it intended to be done in the near future?

Directive 1999/31/EC on the landfill of waste - the Landfill Directive - does not lay down methane emissions ceilings, but provisions for the gas control (Annex I) and for the accumulation and migration of landfill gas (Annex III). The Commission does not envisage in its current work programe any amendment to these provisions. The Commission can initiate infringement proceeding against Member States which allow the operation of landfill sites which are not in conformity with the above mentioned requirements. Only the Court of Justice of the EU can impose fines to Member States as part of such infringement proceedings.

2. What measures will be taken to reduce methane emissions from landfills?

The Waste Package under the Circular Economy (https://ec.europa.eu/environment/circular-economy/index_en.htm) adopted last year introduces a set of provisions which should impact the generation level of methane emissions in landfill sites. For example:

- By 2035, Member States can only landfill 10% of their municipal waste.
- By end 2023, Member States shall ensure the separate collection of bio-waste.
- By end 2023, the Commission will consider a food waste reduction target.

In addition, Member State should continue to enforce Article 5 of the Landfill Directive which requires Member States to set up a strategy and meet the targets laid down therein for the reduction of biodegradable waste going to landfills.

3. Is there a monitoring of methane emissions?

Methane emissions are reported to the UNFCCC in the greenhouse gas emission inventory of the member states of the EU (The results can be found at: https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer).

4. With what instruments is methane detected?

The Landfill Directive does not prescribe such instruments and leaves that choice to Member States.

5. Do you know the satellite technologies for methane detection and use them, or would you be prepared to use them in the future?

There are satellite technologies to provide independent top-down emission estimates of methane emissions at regional or national scale in areas that are sufficiently covered by atmospheric observations. The UK and Switzerland already use top-down estimates based on inverse modelling (and satellite data) of national total methane emissions already. The Joint Research Centre of the Commission also used satellite observations to assess methane emissions (https://ec.europa.eu/jrc/en/research-topic/monitoring-climate-and-climate-change).

A.3 Information given by the U.S. Environment Protection Agency (EPA)

The questions asked were: Is there an economical fine for those states (companies) who do not comply the last regulatory action towards methane leaks from Oil and Gas industry? If there is, what is the import of it per cubic meter (or any other volume unit)? If not, is it left to each state to fine them? Would you be interested in space imagery for the detection of methane leaks from wells? Do you already use any satellite for the methane detection?

The response of the EPA's Air website was in charge of Amy Hambrick.

EPA's Office of Air and Radiation establishes requirements to limit air pollution for certain oil and natural gas equipment and processes.

If an affected facility violates the regulation, there could be a federal fine associated with the violation. There are various factors that are considered when determining the amount of the fine for violating the Clean Air Act.
Some states are delegated EPA programs to implement and enforce. Some states may have their own state specific oil and gas regulations. In these cases, a fine for violation could be issued by a state. As you can see, if can get complicated and much of this depends on how federal and state law and enforcement authority are delegated. With that said, EPA's federal regulations currently have requirements in place to find and repair fugitive emissions so any facility subject to those requirements would have to be in compliance.

Generally speaking, EPA is interested in all air emissions data associated with the oil and gas industry and emerging technologies to detect emissions. Fugitive emissions (leaks) are an area we are particularly interested in. In fact in 2016, EPA issued a notice asking for information on emerging technologies for the oil and gas sector; while this is now out of date it highlights our interest in emerging technologies for detecting emissions. At this time, the fugitive emissions requirements are a "find and repair or replace" program using optical gas imaging camera or a hand held monitor that monitor at a component by component level at a specific site. We have found that because of the normal operational venting from well sites is common, when monitoring, we need to identify if the emission is through "normal" venting or if there is an emissions event because of maintenance event (example: pipeline blowdown or pigging) or if the system is upset such as a tank thief hatch that is stuck open or a valve that is malfunctioning.

While EPA does not currently rely on space imagery for methane detection for regulation development or determining compliance, we recognize there could be something to learn from such imagery. There may be other areas of EPA that does use space imagery (example: EPA's Office of Research and Development) or other government agencies that would be interested and or currently rely on space imagery.

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